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RESEARCH ARTICLE

Increasing the strength of cellular lightweight concrete bricks with the addition of bamboo fiber

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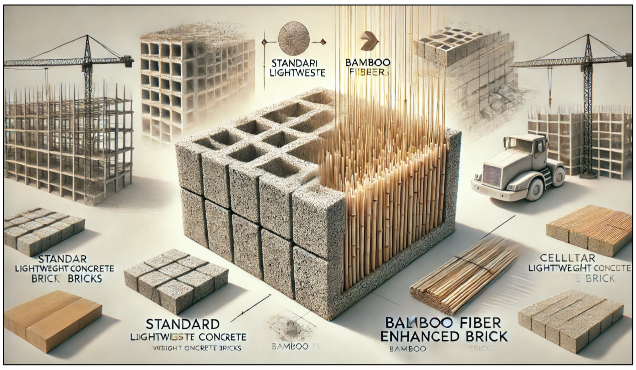

OBJECTIVES This research aims to obtain technology for improving the quality of CLC (Celullar Lightweight Concrete) bricks to be equivalent to AAC (Autoclaved Aerated Concrete). This is a response to the rapid development, especially in the property sector, which is followed by the increasing need for bricks as the main material for building walls. CLC bricks are an alternative product other than red bricks that have the potential to pollute the environment because in the production process there is burning. The problem is that the quality of CLC bricks is relatively lower compared to AAC bricks. METHODS The method is to add bamboo fiber as a reinforcement and optimize the elements. The design of the experiment was made using the Taguchi Method, but preliminary experiments had previously been carried out to predict the percentage of elements. The research includes manufacturing process technology and quality testing on samples. RESULTS Bamboo fiber-reinforced CLC bricks are obtained with an optimal composition of 0.5% fiber and a ratio of cement mass to sand mass of 1:1.6. This sample has a compressive strength of 1.1235 MPa and a bending strength of 1.1723 MPa. From this composition, samples were obtained with an average compressive strength of 1.1285 MPa and an average bending strength of 1.3551 MPa. CONCLUSIONS Thus, it can be concluded that the addition of fiber can increase the strength of CLC bricks to be equal to or stronger than AAC bricks on the market.

KEYWORDS bamboo fiber; bending strength; cellular lighweight concreta; compressive strength

1. INTRODUCTION

In addition to red bricks, currently two other types of bricks are known, namely autoclaved aerated concrete (AAC) and celullar lightweight concrete (CLC). In Greater Jakarta, the portion of AAC and CLC use is around 75%, while outside Java the use is only about 5% of the total brick needs (PT Superior Prima Sukses 2024). Blescon, as a major producer of AAC in Indonesia, reported sales growth of 30% in 2021 and a projected increase to 40% in 2022. It is reported that in 2023, Blescon's production capacity will be 2.7 million m^3 per year (Widarti 2022). In 2024, the construction market growth is predicted to be around 4.68%, which will be followed by an increase in the need for light bricks (Fahmi 2023).

AAC has several advantages when compared to CLC. The main advantages of AAC are that it is stronger and more precise in size. The problem is that AAC is relatively more expensive because it is made from special materials and the fabrication process uses high technology. The main raw materials in the manufacture of AAC are silica sand, cement, lime, gypsum, water, and aluminum powder as bubble generators (Hassan Nensok et al. 2021). The raw materials are mixed and stirred into slurry, poured into large molds, and cut with automatic cutting wire. The next step is the drying and hardening process with an autoclave at a temperature of around 1800 C for 8–12 hours (Goritman et al. 2012).

Unlike AAC, CLC can be made with simple relativity technology, and the raw materials are easy to obtain on the market. The main materials are cement, sand, water, and foam. The foam is made from a mixture of water and foam agent that is pressurized using a compressor. The fabrication process is simpler; it can be done manually, and the drying process is done naturally without autoclave equipment (Ecotrend Materials 2022; Zulapriansyah et al. 2020). Another advantage of making CLC bricks is that it is possible to add other materials as reinforcement, such as fly ash and various

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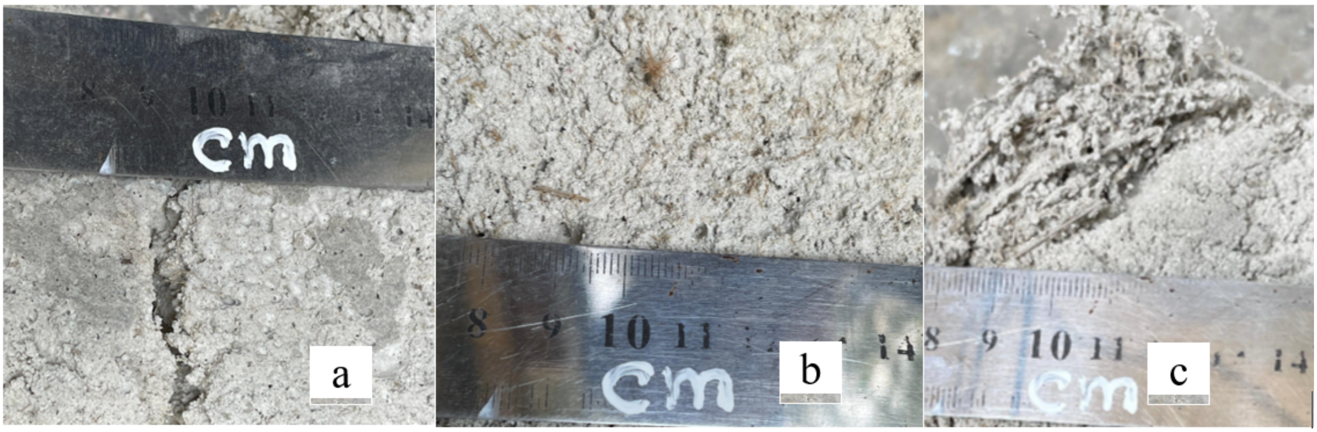


FIGURE 1. Visualization specimens in the preliminary study. (a) short fiber, (b) medium fiber, and (c) long fiber.

reinforcing fibers. Thus, CLC bricks have the potential to be fabricated by small and microbusiness actors.

A lot of research has been done to improve the strength of CLC with the addition of various fibers, for example by adding banana fiber (Hassan Nensok et al. 2021) and adding agave sisalana fiber-PET plastic waste (Widyawati 2020). The use of banana fiber is usually preceded by treatment with NaOH solution. Although it can increase the strength of CLC, this process is wasteful and expensive. In addition, the use of sisalana agave fiber and PET plastic waste can also increase the strength of CLC bricks, but there is not enough data on the reliability of this method because there are no examples of existing products. Unlike banana fiber and agave sisalana fiber, bamboo fiber has been used in construction for a long time (Himasree et al. 2024). Bamboo is a natural material that is environmentally friendly, and bamboo fiber has high strength; it can reach 900–1200 MPa (Li et al. 2023).

Currently bamboo fiber is commonly used for reinforced concrete (Kavitha 2016), but it has not been used as a CLC brick reinforcement. Based on this gap, a study was conducted on the use of bamboo fiber as a CLC brick reinforcement. The research was carried out to obtain the optimal composition for producing maximum strength by varying the ratio of cement, sand, bamboo fiber, and foam. Some samples were made with an experimental design that referred to the Taguchi method (Harsojuwono et al. 2021). Furthermore, a compression test and a three-point bending test were carried out on the samples. This research is targeted to obtain product samples in the form of CLC bricks with quality that meets applicable standards.

2. RESEARCH METHODOLOGY

Previously, a preliminary study had been carried out by trial and error. The preliminary study was conducted simply to see the potential and integrity of the specimen. Samples were made with variations in the amount of fiber, fiber length, and the cement-to-sand ratio. Fiber lengths are made in 3 variations: short (0-30 mm), medium (30-50 mm), and long (50-70 mm) with a thickness of 1-2 mm. From this study, it can be seen that samples with medium fiber sizes have higher strength and even fiber distribution. Short fibers produce brittle specimens, while long fibers tend to clump together and are unevenly distributed, as shown in Figure 1.

2.1 Experimental design

Based on the preliminary study, a two-factor and three-level experimental design was made referring to the Taguchi Method (Harsojuwono et al. 2021), as can be seen in Table 1. This study refers to the SOP for the production of CLC bricks at PT. Brik Koe Jaya Perkasa. To get 1 m^3 of CLC bricks, 350 kg of sand, 180 liters of water, 1 liter of foam agent, and 280 kg of cement are needed (Santoso and Miftah 2023). Sample making is carried out by mixing cement, sand, and water for approximately 10 minutes. The next step is to add wet bamboo fibers, previously washed and soaked in water for 20 minutes, to avoid deep absorption of large amounts of water. Next, add

TABLE 1. Experimental design.

Specimen	Fiber percentage (weight)	Ratio cement to sand (Weight)
1	0%	1:1.2
2	0%	1:1.4
3	0%	1:1.6
4	0.5%	1:1.2
5	0.5%	1:1.4
6	0.5%	1:1.6
7	1%	1:1.2
8	1%	1:1.4
9	1%	1:1.6
Fiber length medium		30-50 mm

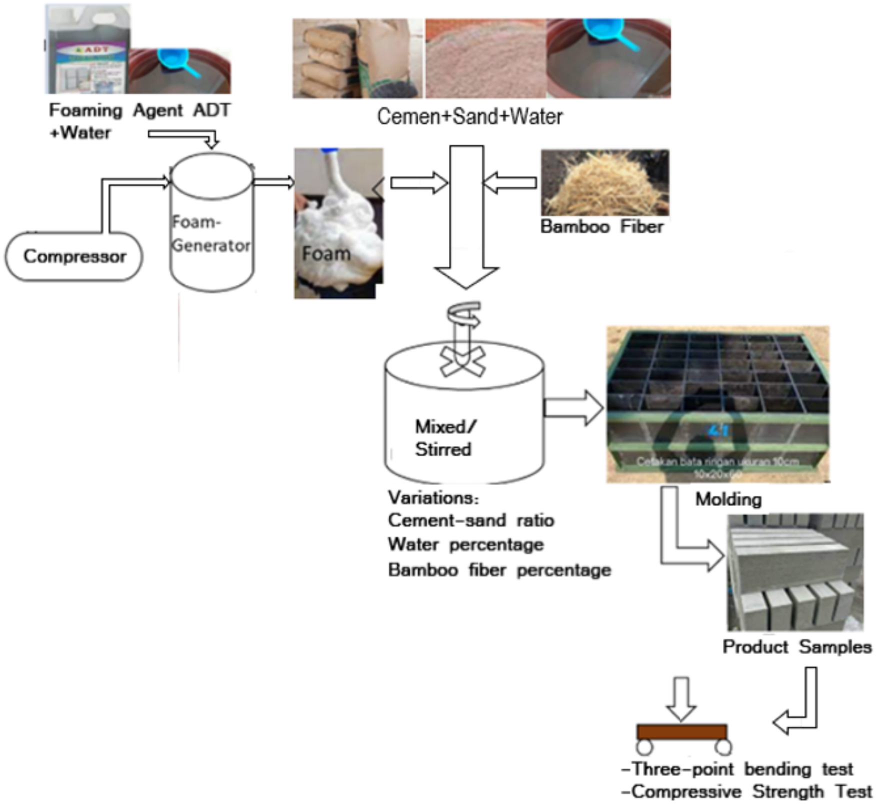


FIGURE 2. CLC lightweight brick manufacturing process.

the foam and keep stirring until evenly distributed. Finally, pour the mixture into the prepared mold. The foam is made from a mixture of foaming agent and water with a ratio of 1:19. The production process is carried out by following the flowsheet as shown in Figure 2.

2.2 Testing procedure

In this study, a compressive strength test and a bending strength test were carried out with test equipment, as can be seen in Figure 3. Compressive strength testing aims to deter-

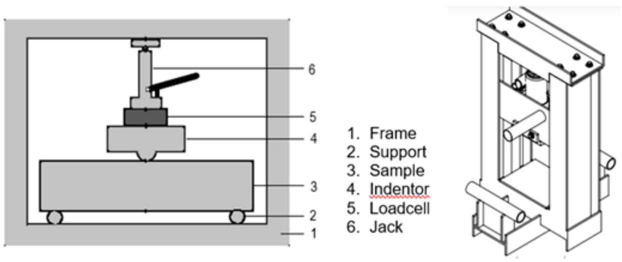


FIGURE 3. Compressive strength test and three-point bending test equipment.

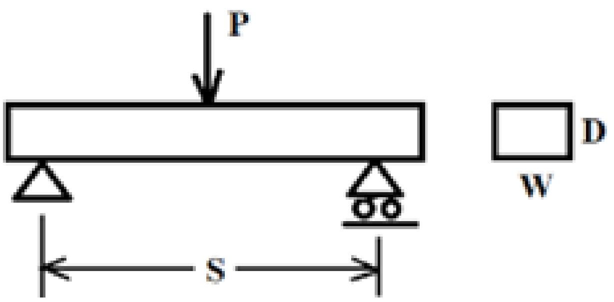


FIGURE 4. Three-point bending test design (American Society of Testing Materials (ASTM) 2017).

FIGURE 5. Test apparatus. (a) Compressive strength test and (b) Three-point bending test.

TABLE 2. Compressive strength, bending strength, and snr.

Sampel	Compressive Strength (MPa)	SNR	Bending Strength (MPa)	SNR
1	0.0903	-20.8878	0.0194	-34.2602
2	0.1599	-15.9199	0.4479	-6.9769
3	0.2356	-12.5561	0.4656	-6.6400
4	0.1014	-19.8815	0.1578	-16.0386
5	0.8910	-1.0025	0.5081	-5.8806
6	1.1235	1.0114	1.1723	1.3808
7	0.1512	-16.4096	0.0726	-22.7870
8	0.3261	-9.7330	0.3081	-10.2272
9	1.0372	0.3170	0.9656	-0.3046
AAC	-	-	0.7624	-

mine the ability of a brick to receive compressive pressure. Compressive strength can be calculated by dividing the maximum load at the time of the crushing test specimen by the cross-sectional area of the specimen. This test refers to SNI 03-2847-2002, 2002. The compression test specimen is in the form of a cube with a size of 15x15x15 cm^3. The compressive strength value is obtained from equation (1), where P is the maximum load achieved.

$$fc = fracPA \tag{1}$$

The bending strength (flexural strength, S_F) and bending modulus (flexural modulus, E_F) can be calculated using Equation (2 and 3), where P_m = maximum load, S = specimen span, D = specimen width, and W = specimen thickness. The

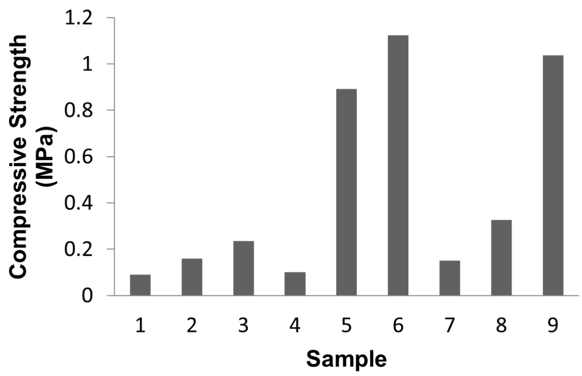


FIGURE 6. Compressive strength.

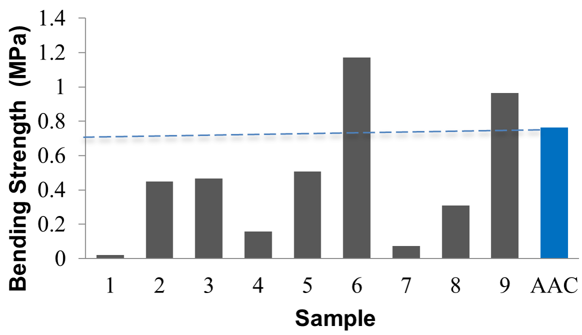


FIGURE 7. Bending strength.

bending test specimen is in the form of a beam with a size of 10x20x60 cm^3.

$$S_f = \frac{3P_m S}{2WD^2} \tag{2}$$

$$S_f = \frac{S^3}{4WD^3} \cdot \frac{\Delta P}{\Delta X} \tag{3}$$

Compressive strength and bending strength tests are performed on the same test apparatus, but the specimens are placed on different support components and different indenter components. Figure 5 shows a photo of a test apparatus for compressive strength and a three-point bending test, respectively.

The experimental data were then analyzed by the ANOVA statistical method. The Taguchi method is used to obtain the optimal composition to obtain the highest strength of the product. By comparing variants between data groups, ANOVA identified factors that interacted in influencing the strength of the samples. From the two variables that have been determined, the maximum value is chosen as the test optimism point. The optimum composition can also be evaluated with the signal-to-noise ratio.

3. RESULTS AND DISCUSSION

Compressive strength testing and three-point bending testing on samples obtained compressive strength and bending strength, respectively, as seen in Figure 6 and Figure 7.

The best composition of the sample is indicated by the Signal to Ratio (SNR) value, where the maximum SNRA value indicates the best composition. Table 2 shows the strength of the samples along with the SNRA value, where sample 6 has an SNRA value of 1.0114 for compressive strength and 1.3808 for bending strength. This sample has a compressive strength of 1.1235 MPa and a bending strength of 1.1723 MPa. In contrast, sample 1 has the most negative SINRA value, meaning that it has the lowest strength for both types of tests. It can be seen that sample 1, which is the weakest sample, does not contain fiber, while sample 6, which is the strongest sample, contains 0.5% fiber. From this analysis, it can be stated that the addition of fiber is proven to increase the strength of CLC lightweight bricks.

To see the factors that affect product quality, a variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Fiber Percentage	2	0.453	0.22648	2.81	0.173
Cement and Sand Ratio	2	0.7028	0.35139	4.36	0.099
Error	4	0.3223	0.08057		
Total	8	1.478			
Model Summary					
S	R-sq	R-sq(adj)	R-sq(pred)		
0.283848	78.20%	56.39%	0.00%		

FIGURE 8. Bending strength.

TABLE 3. Replica testing for compression strength.

Sample	Replicate test results (MPa)			Mean	Standar Deviation
	1	2	3		
5	0.770033	0.773851	0.772399	0.772094	0.001927
6	1.057984	1.26931	1.12885	1.152048	0.107556
9	1.224721	0.960529	0.958729	1.047993	0.153053

analysis (ANOVA) was carried out. Figure 8 and Figure 9 show ANOVA analysis for the compression test and the three-point bending test, respectively. In this test, the loading is applied centrally to a beam-shaped test piece, a common method used to measure the compressive strength of construction materials. The influencing factors are the composition of the material, which includes fiber percentage, fiber size category, and cement to sand ratio.

In the compressive strength test and the three-point bending test, the analysis results showed that the percentage of fiber and the ratio of cement to sand were significant factors. The most influential percentage of fiber is 0.5%, and the most optimal ratio of cement to sand is 1:1.6. This shows that the addition of fiber and the right cement-to-sand ratio can significantly increase the bending and compressive strength of CLC bricks.

The addition of bamboo fiber composition in concrete has been shown to significantly increase bending strength because the fibers serve as a reinforcing force that resists the tensile stress on the material (Sonar and Sathe 2024). In addition, the right ratio of cement to sand can increase the density and stability of the material, thereby increasing the bending strength (Tihanon Dawood et al. 2016). The dominant elements affecting the strength of the sample can be seen from the main effect plot in Figure 10 and Figure 11, respectively, for the compressive strength test and the bending strength test. It can be seen that the fiber content has an optimal composition at a percentage of 0.5% with a medium size. A higher percentage of fiber can absorb more water and can reduce the strength of the specimen (Yusra et al. 2020). Meanwhile, the ratio of cement to sand has not shown an optimal point, meaning that increasing the strength of the product can still be done by increasing the amount of sand.

Figure 12 and Figure 13 are illustrations of the interaction between factors that affect each other, respectively for compressive strength and bending strength. In the figure, it can be seen that the fiber and the ratio of cement to sand have a significant influence on compressive strength. In addition, it

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Fiber Percentage	2	0.137	0.06848	1.73	0.287
Cement and Sand Ratio	2	0.9292	0.4646	11.77	0.021
Error	4	0.1579	0.03948		
Total	8	1.2241			
Model Summary					
S	R-sq	R-sq(adj)	R-sq(pred)		
0.198685	87.10%	74.20%	34.69%		

FIGURE 9. Bending strength.

TABLE 4. Replica testing for bending strength.

Sample	Replicate test results (MPa)			Mean	Standar Deviation
	1	2	3		
5	1.014547	1.14837	0.92479	1.029236	0.112511
6	1.287465	1.43514	1.34278	1.355128	0.074608
9	1.108066	0.973883	1.03548	1.039143	0.067166

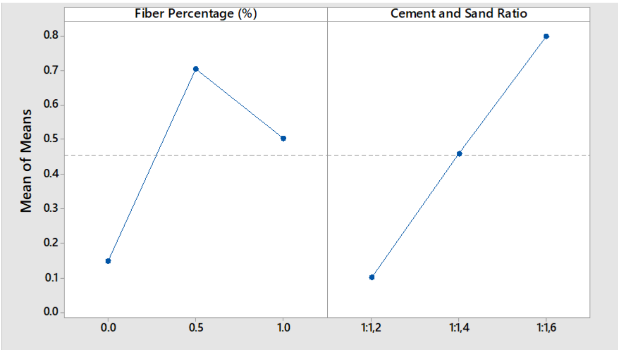


FIGURE 10. Main effects compressive test.

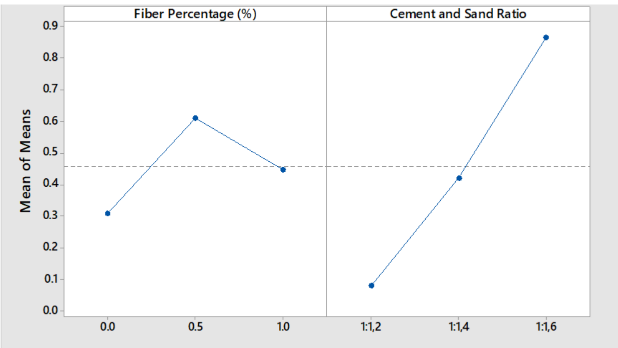


FIGURE 11. Main effect plot bending test.

can be seen that the larger the composition of the sand, the higher the compressive strength. This can be explained by the fact that the sand can fill the voids that occur. In terms of fiber types, medium-sized fibers show the most significant influence on compressive strength. It can be explained that long-size fiber and short-size fiber can absorb a lot of foam, which reduces its effectiveness in increasing the compressive strength of bricks.

To determine the level of repeatability of the test results,

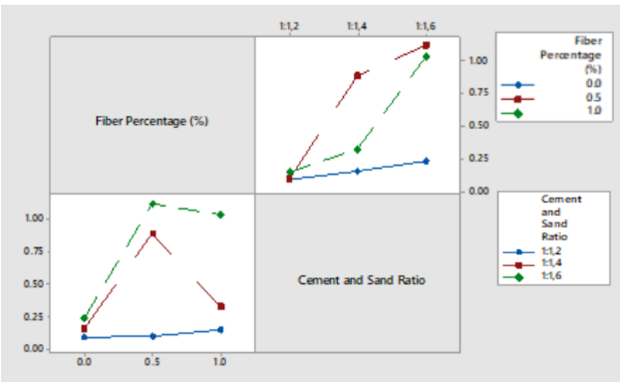


FIGURE 12. Interaction plot compressive test.

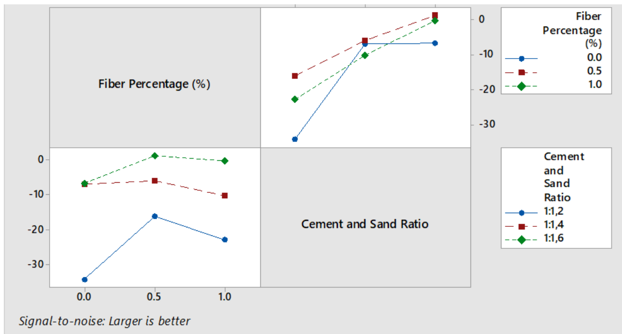


FIGURE 13. Interaction plot bending test.

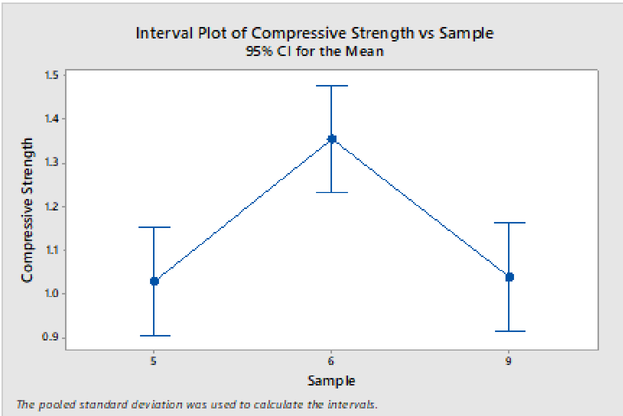


FIGURE 14. Interval plot of compressive strength.

each of the strongest samples (samples 5, 6, and 9) was made into three replicas. The test results can be seen in Table 3 and Table 4, Replica testing for compression strength and Replica testing for bending strength, respectively.

The standard deviation for the compressive strength test and the bending strength test can be seen in Figure 14 and Figure 15, respectively. The plot interval graph is useful to explain the consistency of the test results. The low standard de-

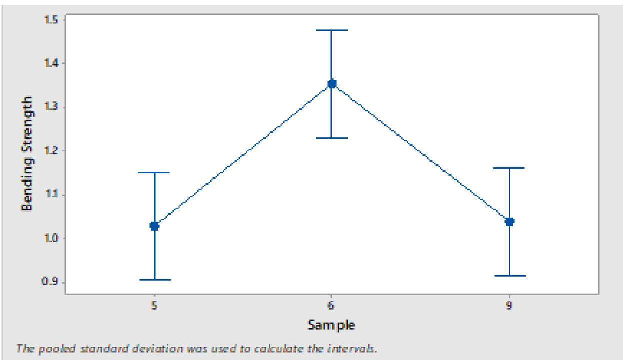
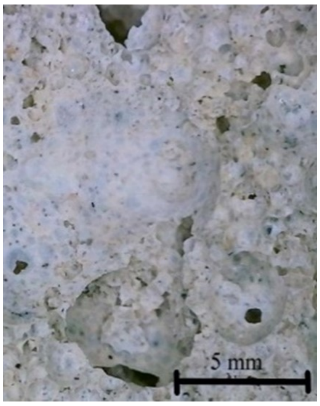
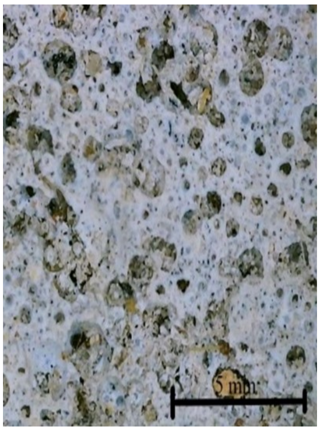


FIGURE 15. Interval plot of bending strength.



(a)



(b)

FIGURE 16. Observation of Sample Microstructure (a) No fiber/Sample 1 (b) With fibers/Sample 6.

(a)

(b)

FIGURE 17. Three-Point Bending Test Process (a) without Fibers/Aample 1, (b) with Fibers/Sample 6.

viation in the test results shows that the test method and material composition used are consistent and reliable (Belouafa et al. 2017).

In this study, the microstructure of the sample was also observed with a 125x magnification scale camera. Figure 16 shows the microstructure of the sample: (a) the microstructure of the fiberless sample (sample 1) and (b) the microstructure of the fibrous sample (sample 6). In fibrous samples, empty cavities are seen with relatively large and non-uniform sizes. In contrast, in fibrous samples, the cavity size is relatively small and uniform. The addition of fiber affects the size of the cavity because the fiber can break up large bubbles with its capillary properties.

Figure 17. Featuring the three-point bending test process (sample 1) observed with a 125x magnification scale. In Figure 17a, it is observed that the fiberless sample has a pattern of sudden failure. In contrast to that, in Figure 17b, it can be seen that the sample failure pattern is obstructed by fibers. Factors such as fiber percentage and cement-sand ratio have a significant effect on bending strength because fibers can increase the material's resistance to tensile stress, while sand provides a more stable structure. However, at compressive strength, the effect of fibers is not very significant because the compressive strength is more affected by the density and compactness of the material than its resistance to tensile stress. Further discussions on the optimization of the cement-to-sand ratio need to be carried out to find the optimum point that produces the best mechanical properties. Further research can be done by trying more specific variations in the ratio to find the most optimal composition.

3.1 Conclusions

This study produced CLC bricks from cement, sand, water, foaming agent, and bamboo fiber, with an optimal composition consisting of a fiber weight of 0.5% and a cement to sand weight ratio of 1:1.6. From this composition, product samples were obtained with an average compressive strength of 1.1285 MPa and an average bending strength of 1.3551 MPa. A fiber percentage higher than 0.5% can reduce the strength of the specimen due to the fact that the fiber can absorb more water and the drying process becomes faster. Meanwhile, the ratio of cement to sand has not shown an optimal point, meaning that increasing the strength of the product can still be done by increasing the amount of sand. Further research is needed to find the optimal composition in order to obtain the best mechanical properties that meet the standards. Further research can be carried out with more specific ratio variations.

3.2 Acknowledgements

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