Chemical Treatment of Agricultural Waste Fibers from Pineapple Leaves and Manila Hemp used in Fiber-Reinforced Concrete Hollow Blocks

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Abstract: This research examines how chemically treated agricultural waste materials such as pineapple leaf and manila hemp (also known as Abaca) can affect the performance of concrete hollow blocks that are reinforced with fiber. The goal of this work is to find eco-friendly options for building materials due to the problems created when disposing of agricultural waste. The fiber is blended together in a 50/50 ratio (half pineapple and half manila hemp) and added to the concrete hollow blocks at varying amounts (0.25%, 0.50%, 0.75% and 1.00% by weight of cement), with a control mix containing no fiber. To help with adhesion between the fiber and the matrix, to reduce the water absorbed by the fibers and to improve durability, the fibers were chemically treated with a 4% sodium hydroxide solution. During the experimental procedure, composite mixtures were prepared, cast into molds, cured (7, 14 and 28 days) and tested to determine their compressive strength, density, workability, impact resistance (drop test) and cost effectiveness. A statistical analysis of the data collected is also be conducted to determine the optimum fiber amount. The findings showed that the addition of 0.25% of the fiber to the concrete hollow blocks resulted in an increase in compressive strength early in the curing process as well as providing the best overall performance compared to the other mixtures tested. Increasing the fiber amount to levels above 0.25% resulted in less workability of the mixture, clustering of fibers, more voids within the concrete and ultimately a decrease in compressive strength. The control mix was found to have greater strength during the latter part of the curing process, which is due to the inherent poor grading of the fine aggregates used in the study and not due to the presence of the fibers. Additionally, specimens made with fiber reinforcement exhibited improved crack and impact resistance with lower fiber percentages. To summarize, the results of this study indicate that chemically treated pineapple leaf and manila hemp fibers exhibit sufficient strength as reinforcement for non-load bearing concrete hollow blocks when used in optimum amounts. The research findings expand on the body of knowledge related to developing sustainable, cost effective and environmentally friendly building materials and confirm gaps in previous research regarding the use of hybrid natural fibers systems for concrete hollow block applications.

Highlights

- Hybrid PALF and abaca fibers were successfully modified using 4% NaOH treatment.
- A 0.25 wt% fiber inclusion optimizes the compressive strength of hybrid CHBs.
- Higher fiber volume fractions (>0.50%) induce clumping and structural voids.
- Anomalous fine aggregate gradation governs absolute compressive limits.
- Multi-criteria analysis maps the trade-offs between cost and eco-efficiency.

Keywords: Concrete hollow blocks (CHB), Fiber reinforcement, Pineapple leaf fiber, Manila hemp (Abaca) fiber, Sodium hydroxide treatment (NaOH), Compressive strength, Sustainable building materials

1. Introduction

The application of natural fibers in concrete technology has received much focus in recent times because of the requirement of sustainable building materials. Natural agricultural residues such as pineapple leaf fiber and abaca fiber are readily available in most parts of the world, but they are usually burned or dumped, thereby polluting the environment. Utilizing these fibers in concrete provides an effective means of waste management while improving the mechanical performance of cement-based composites (Karolina et al., 2022; Che Osmi et al., 2022).

Pineapple leaf fiber (PALF) has been considered as a potential reinforcement because of high tensile strength, low density and good stiffness. It has been reported that the incorporation of PALF can enhance crack resistance and ductility in concrete by bridging microcracks and arresting crack growth (Aboo Jacob et al., 2022; Kayibanda et al., 2019). Nevertheless, high fiber content may have an adverse influence on workability and cause low compaction with the resulting decrease in compressive strength (Che Osmi et al., 2022).

Likewise, abaca fiber or manila hemp has been known for its good tensile and durable properties. Anthony et al. (2020) abaca fibers reinforced concrete had higher compressive and tensile strengths, and energy absorption ability than the control specimens. Lee and Choi (2022) also indicated that the abaca fibers reduce autogenous shrinkage as well as increase the dimensional stability of in cement composite, but high content of fiber leads to fiber clustering and decrease workability.

One of the major limitations in using natural fibers in concrete is their compatibility with the alkaline cementitious matrix. Untreated fibers have high water absorption and gradually deteriorate, leading to poor fiber–matrix adhesion and lower durability (Vodounon et al., 2018). To meet the problem, chemical applications such as sodium hydroxide (NaOH) treatment have been commonly used to eliminate surface impurities and generate roughness on fiber surfaces.

De Leon and Tividad (2016) demonstrated that treated NaOH pineapple leaf fibers improved both flexural and compressive strengths as compared to non-treated fibers. In addition, Malenab et al. (2017) demonstrated that treatment with an alkaline solution improved the interfacial bonding between fibers and reduced water absorption, which contributed to improved mechanical and durability characteristics of abaca fibers.

In recent years, researchers have discovered that when using various types of natural fibers together in a cement composite, it can produce a synergistic relationship. Da Silva et al. (2025), stated that the hybrid nature of these systems improves crack resistance, toughness, and durability through the additive attributes of each individual fiber type. However, much of this current body of knowledge focuses on single-fiber systems; therefore, very little research exists that examines the use of pineapple leaf fiber and abaca fiber used together in concrete hollow blocks.

Hence, there is a need to investigate the combination of chemically treated pineapple leaf fiber and abaca fiber to determine its impact on the performance characteristics of concrete hollow blocks. The goal of this research is to determine the influence of both pineapple leaf fiber and abaca fiber on the performance of concrete hollow blocks in terms of compressive strength, durability, workability, and cost-effectiveness and contribute to the development of sustainable, locally available construction materials.

2. Methodology

A. Research Method

The study employed a mixed-methods approach incorporating quantitative laboratory testing and qualitative workability assessment. Compressive strength, density, and impact resistance were evaluated using standardized testing procedures, while descriptive statistics and one-way ANOVA were applied to determine the optimum fiber content.

B. Research Design

The study utilized an experimental research design to evaluate the performance of chemically treated Pineapple Leaf Fiber (PALF) and Manila Hemp (Abaca) fibers as reinforcement materials for concrete hollow blocks (CHBs). Conventional CHBs served as the control specimens, while varying fiber contents were incorporated into the experimental mixtures.

C. Research Instrument

ASTM C140/C140M was used to evaluate compressive strength and density, while ASTM C136/C136M was applied for sieve analysis of fine aggregates. Impact resistance was evaluated using a drop test procedure to assess the mechanical performance of fiber-reinforced CHBs

D. Locale of the Study

The research was conducted across three locations. Density, sieve, and compression tests were performed at the College of Engineering and Architecture Laboratory of the University of the Assumption in San Fernando City, Pampanga. Concrete mixtures were prepared and CHB samples cast at RSG 620 Construction in San Miguel, Mexico, Pampanga, where initial curing was carried out by water spraying before transport to San Vicente, Mexico, Pampanga for final curing. The curing process was conducted at a home to allow for proper space for curing, after which the samples were brought back to the University of the Assumption at 7, 14, and 28 days for compressive strength and mass testing on the Universal Testing Machine (UTM).

E. Process Flow Chart

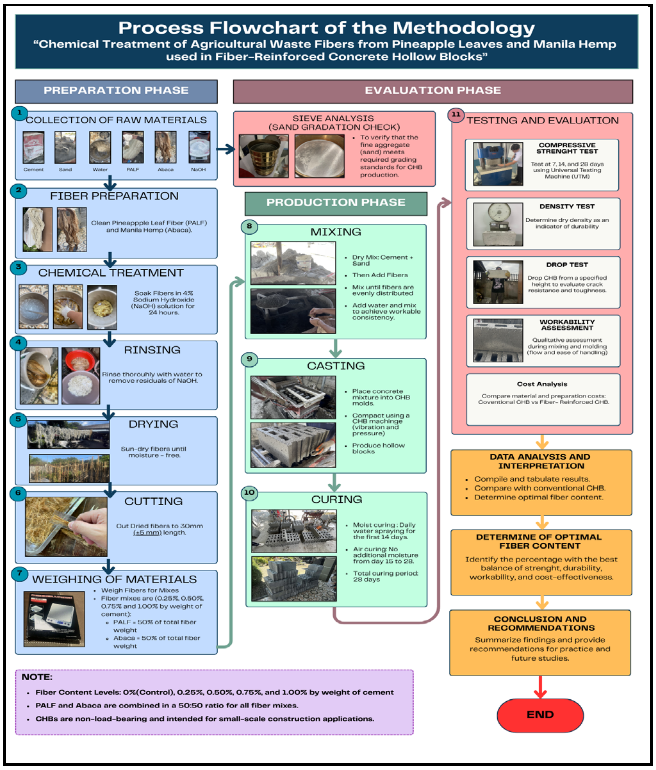


Fig.1. *Process Flow Chart*

F. Material Preparation

The materials used in this study include Ordinary Portland Cement, fine aggregate (sand), Pineapple Leaf Fiber, Manila Hemp fiber, sodium hydroxide (NaOH), and water. The fibers were obtained from locally available agricultural sources and prepared prior to mixing.

1) Cement

Ordinary Portland Cement (OPC) was used as the primary binding material.

2) Sand

Fine aggregate (sand) was used to improve mixture stability and workability.

3) Water

The water was utilized for both in fiber mixture as well as mixing and curing of the mixes and aids in the hydration of cement which is the basis for establishing strength and durability in concrete.

4) Pineapple Leaf Fiber

Pineapple Leaf Fiber (PALF) was utilized as a natural reinforcing material for the CHBs.

5) Manila Hemp Fiber

Manila Hemp (Abaca) fiber was incorporated to improve toughness and crack resistance.

6) Sodium Hydroxide

A 4% sodium hydroxide (NaOH) solution was used to chemically treat the fibers and improve fiber–matrix bonding.

G. Fiber Preparation and Chemical Treatment

The Pineapple Leaf Fiber and Manila Hemp fibers are cleaned to remove dirt and impurities and cut into uniform lengths. The fibers were immersed in a 4% sodium hydroxide (NaOH) solution for 24 hours to improve fiber–matrix bonding. After soaking, the fibers are thoroughly rinsed with water to reduce alkali residue and subsequently sun dried.

1) Ratio of Fibers

These designated fiber contents are calculated according to the weight of cement. The combination of the fibers that is present in the compound consists of Pineapple Leaf Fiber (PALF) and Manila Hemp (Abaca) in a **ratio of 1:1 (50% PALF and 50% Abaca)**. For instance, the concentration of the fibers at 1.00% can be expressed as 0.50% PALF and 0.50%

2) Fiber Length

In the experiment, the length of the fibers was standardized to **30 mm** ± 5 mm.

3) Alkali Treatment

The natural fibers were soaked in a 4% NaOH for a period of 24 hours. This process was intended to remove contaminants such as lignin and hemicellulose from the natural fibers so that the fibers could be in contact with concrete on a more even surface than before alkali treatment and provide better roughness for bonding.

4) Water Treatment

The treated fibers were rinsed with potable water to eliminate the residual alkali that remained after the alkali treatment process.

5) Drying Method

Before being mixed, the treated fibers were allowed to dry in direct sunlight until they reached a constant weight or moisture content.

H. Concrete Mixing and Procedure

Once the specimens had been initially cured in water, they were allowed to air dry in order to represent practical conditions used to produce concrete hollow blocks (CHB).

1) Mix Proportioning

The CHB mixes contained four different amounts of fiber content of 0% (control), 0.25%, 0.5%, and 0.75 percent by weight of cement. The control mix did not contain any fiber reinforcement.

2) Mixing Procedure

Mix all dry materials before adding the chemically treated fibers, in order to minimize clustering of the fibers and help ensure an even distribution of fibers throughout the mix.

3) Molding and Compaction

The prepared mixes were molded into standard dimensions for CHBs and compacted using vibration methods, to remove internal voids and increase uniformity of the specimens.

4) Water Curing

During the first 14 days of curing, specimens were cured by spraying the specimens with water every four hours, until 6:00 PM.

5) Air Curing

Specimens were moved from water curing conditions to air curing conditions from 15 days to 28 days.

I. Testing Ages

This means that concrete specimens were tested for compressive strength, and Density test at 7,14, and 28 days and drop tests were conducted at 28 days.

J. Data Gathering Procedure

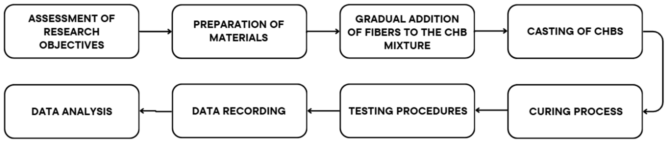


Fig. 2. *Data Gathering Procedure*

Compressive strength, density, impact resistance, and workability of the fiber-reinforced concrete block (CHB) specimens were prepared, cured, and tested. Performance evaluation was performed by collecting experimental data and then analyzing the data obtained.

K. Data Collection

Using a predetermined mix design, Concrete Hollow Blocks (CHBs) were produced with a control mix (0%) as well as 0.25%–1.00% Pineapple Leaf Fiber (PLF)–Abaca mixtures in increments of 0.25% to 1.00% by cement weight, which were referred to as fiber-reinforced specimens. During the mixing phase, the fibers were added gradually to ensure equal mixing throughout the bat. The materials were mixed dry before the addition of the water and fibers, and then molded on a mechanized CHB production machine via vibration compaction. Before curing, the workability and surface finish properties of the CHBs were recorded. The CHBs underwent greenhouse curing using sprayed water for the first 14 days of the curing process. For the final 14 days of curing, the CHBs were air cured under the same environmental conditions for a total of 28 days of curing. Mechanical performance was assessed using compressive strength, density and impact resistance tests. The compressive strength and density were measured according to ASTM C140/C140M using a Universal Testing Machine; the impact resistance was evaluated through an experimental drop test on 28-day specimens from a drop height of 1.5 m. The CHBs were considered to have failed if they broke, had large cracks, spalled or were deformed due to an impact. The sieve analysis on the fine aggregates was performed according to ASTM C136/C136M using sieves numbered 8–200, and the results were used to characterize the materials being used. Mixing and molding data provided information about mixing and molding processes as well as qualitative information on the mixing and molding workability and a comparative cost analysis between conventional CHBs and fiber reinforced CHBs.

L. Statistical Analysis

Statistical analyses utilizing descriptive and inferential statistics were utilized to analyze the collected data. Computed means and standard deviation for compressive strength, density and impact resistance were computed. A one-way Analysis of Variance (ANOVA) was performed to identify differences across fiber content at the 0.05 level of significance. Workability was qualitatively evaluated based on mixing ease, consistency, and moldability during manufacturing. In addition to the descriptive and inferential statistical analyses, a multi-criteria evaluation technique was used to identify the optimal fiber blend on the basis of compressive strength, density, impact resistance, workability and cost.

3. Result and Discussion

A. Sieve Analysis of Fine Aggregates

Table 1
Determination of size distribution of fine aggregates

Sieve No.	Weight Retained	% Retained	% Passing
8	49.67	16.58%	83.42%
16	55.67	18.58%	64.84%
30	124.33	41.49%	23.35%
50	63.67	21.25%	2.10%
100	5.33	1.78%	0.32%
200	1	0.33%	Approx 0%
Pan	0	0%	Approx 0%
Total	299.67		

The sieve analysis results revealed that the fine aggregates used in the study exhibited poor gradation characteristics. Improper particle size distribution may have contributed to the lower compressive strength values observed in both the control and fiber-reinforced CHB specimens. Poorly graded aggregates can produce excessive voids within the concrete matrix, resulting in reduced compaction and weaker interparticle bonding.

B. Workability of Concrete Mixture

Table 2
Description and Classification of Workability

Fiber Content	Workability Observation
0%	Smooth and workable
0.25%	Slightly reduced workability
0.50%	Noticeable stiffness
0.75%	Fiber clumping observed
1.00%	Difficult mixing and molding

Table 2 presents the increasing of fiber content reduced the workability of the concrete mixtures. Higher fiber percentages caused fiber clustering and reduced the uniformity of the mix. The 0.25% fiber mixture maintained acceptable workability, while mixtures above 0.50% became increasingly difficult to compact and mold properly.

C. Density of CHB Specimens

Table 3
Density of CHB Specimens

Fiber Mix	7 Days	14 Days	28 Days
0	1078.73	1113.86	1092.81
0.25	1087.68	1112.02	1093.51
0.5	1123.18	1127.81	1103.6
0.75	1076.75	1095.48	1070.46
1	1070.09	1092.8	1091.23

Results from Table 3 show that average density values of concrete hollow block (CHB) specimens made with chemically treated Pineapple Leaf Fiber (PALF) and Manila Hemp fibre are lower than similar blocks made of concrete alone and that higher fiber content results in lower density of CHBs. The highest density of a control specimen is due to the ability to pack and consolidate concrete particles without the introduction of fiber reinforcement. The CHB specimens containing fiber reinforcement exhibited lower density due to the lower specific gravity of natural fibers as well as the presence of large amounts of internal voids within the concrete structure. While the lowest fiber content (0.25%) produced a fairly consistent density value, indicating that the fiber was dispersed well, the increased fiber content caused the fibers to agglomerate (clump together), resulting in reduced workability and improper consolidation of the mixture during the molding stage. These factors all contributed to a lower density value for the fiber-reinforced

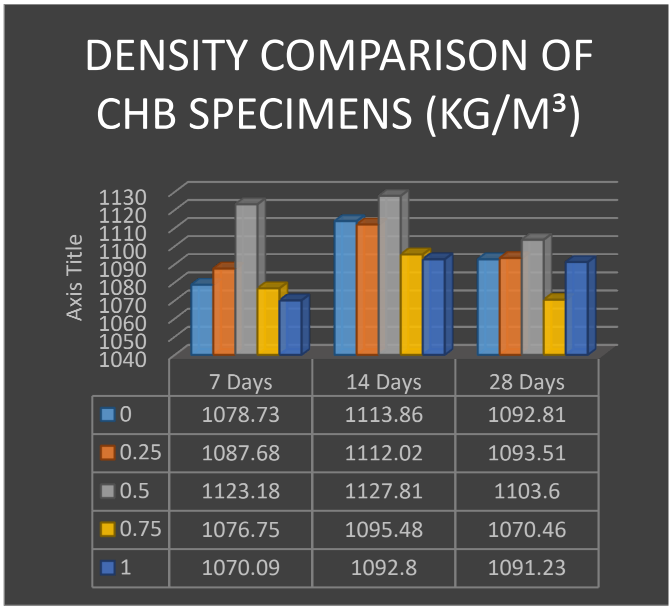
Table 4

Summary of Compressive Strength Results of Fiber-Reinforced CHBs

Fiber Mix (%)	Net Area (m²)	7 Days (MPa)	Difference from Control	14 Days (MPa)	Difference from Control	28 Days (MPa)	Difference from Control
0	0.076	0.3618	—	0.6643	—	0.509	—
0.25	0.076	0.4422	0.0804	0.4754	-0.1889	0.523	0.014
0.5	0.076	0.4118	0.05	0.3747	-0.2896	0.359	-0.15
0.75	0.076	0.2201	-0.1417	0.3826	-0.2817	0.215	-0.294
1	0.076	0.2368	-0.125	0.4264	-0.2379	0.27	-0.239

mixtures when compared to the control specimens.

The observed reduction in density corresponds with the compressive strength behavior of the CHB specimens, where mixtures with lower density generally exhibited lower compressive strength performance.



	7 Days	14 Days	28 Days
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1	1070.09	1092.8	1091.23

Fig.3. Density Comparison of CHB Specimens

Figure 3 shows the density of both the control and fiber-reinforced CHB specimens. As fiber content increases, it becomes evident that the density decreases. This effect is even greater at fiber contents of more than 0.50%, when the fibers tend to cluster together and thus create a less workable mixture. The 0.25% fiber content produced density values that were only slightly lower than those of the control specimens, indicating that the addition of low amounts of fibers will still produce a reasonably compacted mixture and the same type of construction uniformity as that of non-fiber reinforced CHB specimens. However, the presence of large fiber amounts results in a substantial number of void spaces forming in the concrete mixture. The trending density results also support the compressive strength results from the current study, which demonstrate that the degree of compaction and density of the fiber reinforced CHB specimens were significant in relation to their mechanical performance.

D. *Compressive Strength of CHBs*

The compressive strength properties of the CHB specimens made with varying percentages of combined natural fibers (50% Manila Hemp and 50% Pineapple Leaf Fiber) were analyzed at 7, 14 and 28 days of curing. The results of the fiber reinforced mixtures were then compared to the control specimen (with 0% fiber content) in order to assess the effect of fiber addition on the mechanical properties of the CHB specimens, as related to the degree of mechanical behavior.

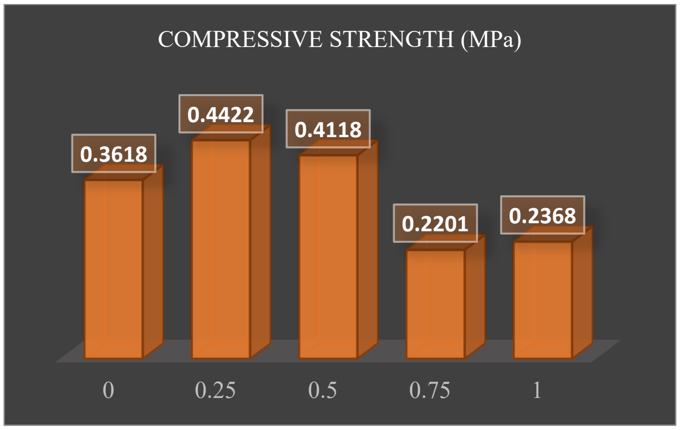


Fig.4. 7-Day Compressive Strength of CHBs

Figure 4 shows that the addition of 0.25% natural fiber resulted in the highest 7-day compressive strength. This suggests that low fiber content improved early-age bonding and crack resistance within the CHB matrix. However, increasing the fiber percentage beyond 0.50% caused a reduction in strength due to poor compaction and increased void formation.

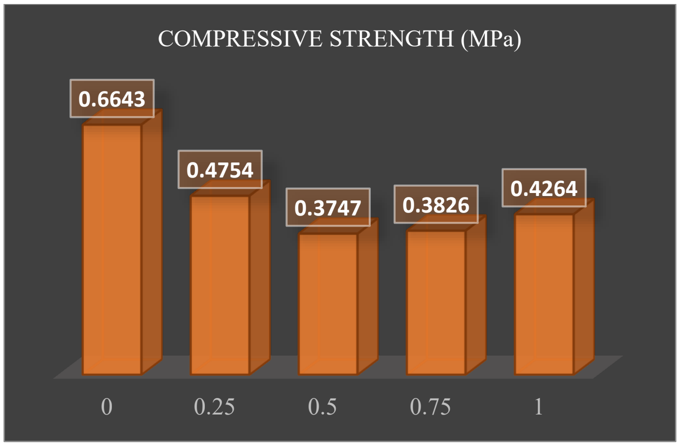


Fig.5. 14-Day Compressive Strength of CHBs

Figure 5 indicates that the control specimen obtained the highest compressive strength at 14 days. All fiber-reinforced CHBs produced lower strength values compared to the control mix. This may be attributed to the interference of fibers with cement paste densification and internal bonding during the curing process.

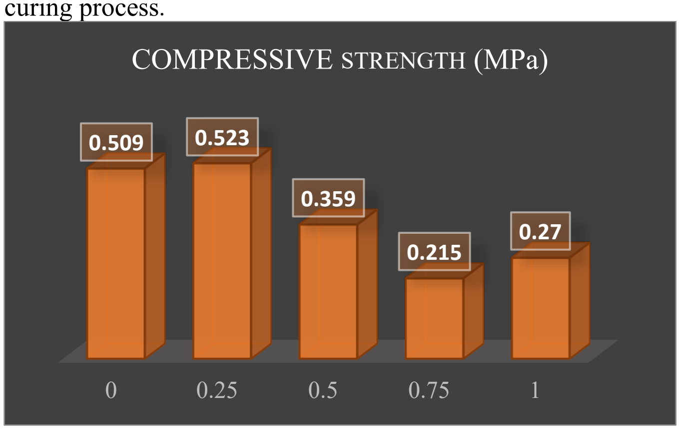


Fig.6. 28-Day Compressive Strength of CHBs

As shown in Figure 6, the 0.25% fiber mix achieved the highest 28-day compressive strength among all fiber-reinforced samples and slightly exceeded the control specimen. This demonstrates that a minimal amount of natural fiber can improve long-term performance. However, higher fiber contents significantly weakened the CHBs due to fiber agglomeration and poor matrix cohesion.

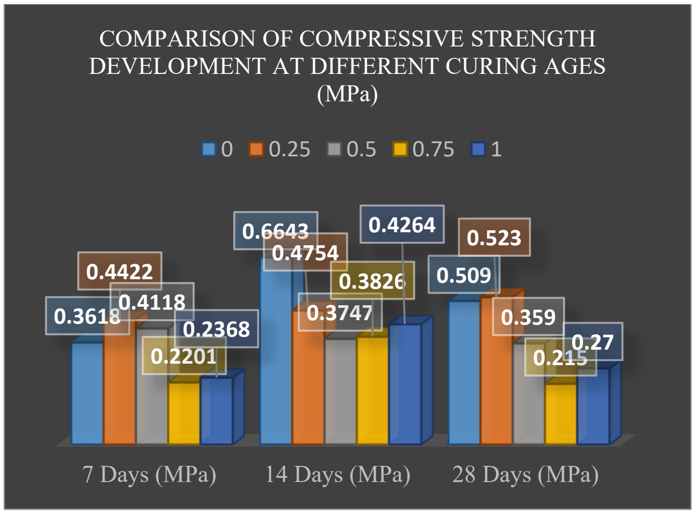


Fig.7. Comparison of Compressive Strength Development at Different Curing Ages

Figure 7: illustrates the compressive strength development of CHBs at different curing periods. The control mix demonstrated the highest overall strength development, particularly at 14 days. Meanwhile, the 0.25% fiber mix consistently performed better than the other fiber-reinforced mixtures, indicating that low fiber addition provides the most balanced performance.

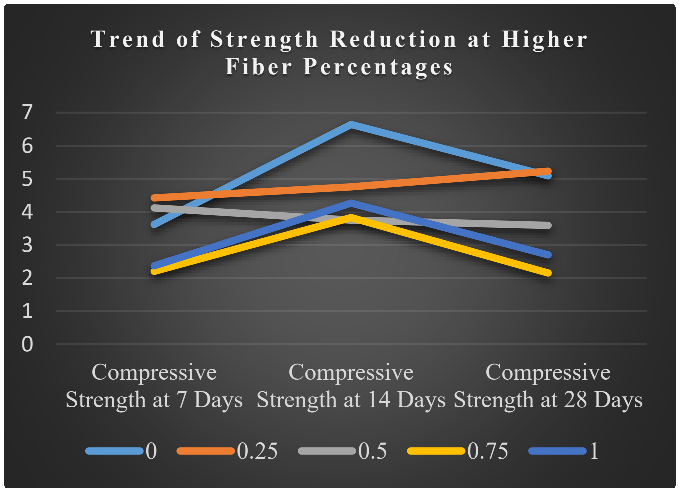


Fig.8. Trend of Strength Reduction at Higher Fiber Percentages

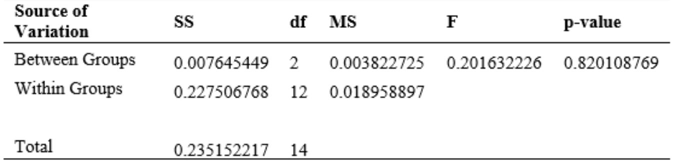
Figure 8: shows a general decline in compressive strength as fiber content increased above the optimum level of 0.25%. Excessive fiber addition likely caused inadequate compaction, uneven fiber distribution, and increased porosity within the CHBs, leading to reduced structural integrity and lower load-bearing capacity.

E. Hypothesis Testing

1) One-Way Anova

An appropriate statistical tool for determining whether there is a significant difference among the compressive strengths of three or more sample groups is the one-way Analysis of Variance (ANOVA). This statistical test determines whether the observed variations among group means are caused by random chance or by actual differences among the sample groups. The test gave an F-value of 0.2016, indicating that there were no significant differences between the compressive strength of the control blocks and those with varying amounts of fiber at 7 days. The test results for 14 days and 28 days also gave p-values greater than 0.05, showing no significant differences among the control group and the groups with fiber. Therefore, it can be concluded that the use of PALF and Manila Hemp fiber has no significant impact on the compressive strength of CHB during each of the curing times tested.

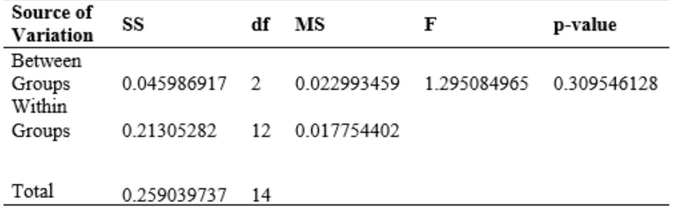
Table 5
One-Way ANOVA for 7-Day Compressive Strength



Source of Variation	SS	df	MS	F	p-value
Between Groups	0.007645449	2	0.003822725	0.201632226	0.820108769
Within Groups	0.227506768	12	0.018958897		
Total	0.235152217	14			

The 7-day compressive strength test returned a p-value of 0.8201, which is greater than the 0.05 level of significance. The 14-day compression strength tests were evaluated using the one-way ANOVA statistical significance testing method. Therefore, the null hypothesis (H0) has been accepted.

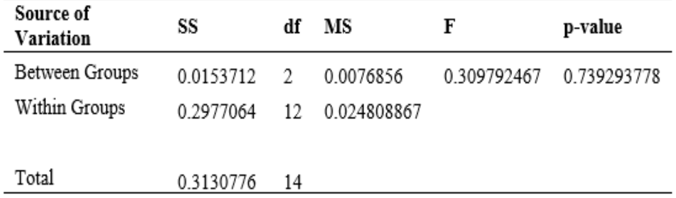
Table 6
One-Way ANOVA for 14-Day Compressive Strength



Source of Variation	SS	df	MS	F	p-value
Between Groups	0.045986917	2	0.022993459	1.295084965	0.309546128
Within Groups	0.21305282	12	0.017754402		
Total	0.259039737	14			

The ANOVA results for the one-way ANOVA compressive strength test at 14 days was found by obtaining the p-value of 0.3095, which is greater than the 0.05 level of significance. Based on this data, there are no significant differences in compressive strength between the various fiber percentages used in this study. Therefore, the null hypothesis (H0) has been accepted.

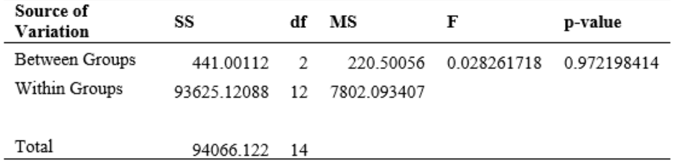
Table 7
One-Way ANOVA for 28-Day Compressive Strength



Source of Variation	SS	df	MS	F	p-value
Between Groups	0.0153712	2	0.0076856	0.309792467	0.739293778
Within Groups	0.2977064	12	0.024808867		
Total	0.3130776	14			

The ANOVA result for the 28-day compressive strength test showed a p-value of 0.7393, which is greater than the 0.05 level of significance. This indicates that there is no significant difference among the compressive strengths of the different fiber mixture percentages. Therefore, the null hypothesis is accepted.

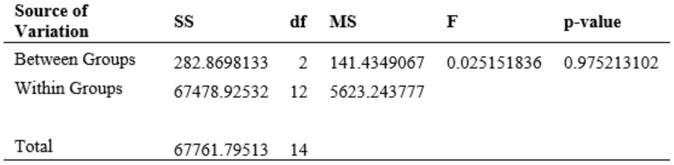
Table 8
One-Way ANOVA for 7-Day Density



Source of Variation	SS	df	MS	F	p-value
Between Groups	441.00112	2	220.50056	0.028261718	0.972198414
Within Groups	93625.12088	12	7802.093407		
Total	94066.122	14			

The one-way ANOVA conducted for the 7-day density test yielded a p-value greater than the 0.05 level of significance. Therefore, the null hypothesis (Ho) was accepted, indicating that there was no statistically significant difference among the density values of the control and fiber-reinforced CHB specimens at 7 days. Although slight variations in density were observed among the mixtures, these differences may be attributed to minor changes in compaction and fiber distribution during mixing and molding.

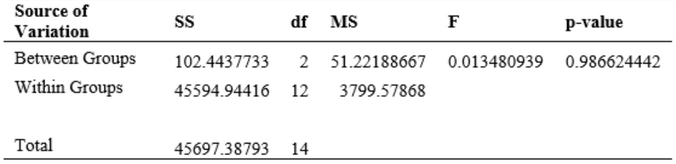
Table 9
One-Way ANOVA for 14-Day Density



Source of Variation	SS	df	MS	F	p-value
Between Groups	282.8698133	2	141.4349067	0.025151836	0.975213102
Within Groups	67478.92532	12	5623.243777		
Total	67761.79513	14			

The results from the statistical analyses performed on the density of the blocks at 14 days using one-way ANOVA also resulted in a p-value of greater than the level of significance, which indicates that there were no significant differences in the density values between the control and the two types of CHB tested after 14 days. It was concluded that the addition of PALF and Hemp fibers did not significantly alter the density characteristics during this curing period.

Table 10
One-Way ANOVA for 28-Day Density



Source of Variation	SS	df	MS	F	p-value
Between Groups	102.4437733	2	51.22188667	0.013480939	0.986624442
Within Groups	45594.94416	12	3799.57868		
Total	45697.38793	14			

Likewise, the one-way ANOVA analysis for the density of the blocks After 28 days indicated a p-value greater than the 0.05 level of significance indicating that there were no significant differences in the density values between the two types of CHB and the control at 28 days. The reduction observed in density with increased fiber content was not statistically significant. The incorporation of chemically treated pineapple leaf and Manila hemp fiber increased the compressive strength and density of the CHB specimens at the 0.05 level of significance. While numerical variations were seen, especially with the 0.25% fiber content exhibiting the highest overall performance, none were statistically conclusive enough to reject the null hypothesis. Additionally, it is evident that in addition to the fiber addition, other factors such as poor aggregate grading, reductions in workability, dispersions of the fiber, etc. also affected the mechanical behavior of the CHBs. However, the data here indicates that for the CHBs exhibiting the highest overall performance regarding compressive strength, impact resistance, and workability, the lower fiber contents, particularly at 0.25%, provided the most balanced performance, and were therefore the most cost effective.

F. Impact Resistance (Drop Test)

Table 11
Impact Resistance (Drop Test) Results of CHB Specimens

Fiber Content	**Crack Observation**	**Failure Condition**	**Impact Resistance Description**
Control Sample (0%)	Partial Break	Failed after impact	Moderate resistance
0.25% Fiber Mix	Minor surface cracks	Remained intact	Improved toughness
0.50% Fiber Mix	1/3 Break	Partial damage	Moderate resistance
0.75% Fiber Mix	Major break, block split into many	Failed after impact	Poor resistance
1.00% Fiber Mix	Major break, block split into three	Failed after impact	Poor resistance

Table 4.9 shows the effect of impact resistance on the control and fiber reinforced concrete hollow block (CHB) specimens that underwent the drop test at 28 days. From this test, it can be seen that the use of chemically treated pineapple leaf (PALF) and manila hemp fiber has improved the crack resistance and toughness of the tested CHB specimens when lower levels of fiber were used. The control specimen experienced brittle failure, as indicated by the presence of major cracks and sudden fracturing caused by impact. As opposed to that, the specimens reinforced with fiber experienced less damage than the control specimens due to the fact that the fibers bridged the cracks that developed within the concrete. The 0.25% fiber content exhibited the most positive impact resistance performance out of all the tested mixtures, as evidenced by the absence of significant damage (other than a small number of superficial surface cracks), while at the same time the specimens remained substantially intact after impact. This may be a function of better dispersion of the fibers in the concrete matrix and a greater capacity for absorbing energy. However, both the higher fiber contents (i.e., 0.50% - 1.00%) resulted in decreased impact resistance due to poor workability, fiber agglomeration, and increased voids created in the concrete of the CHB specimens. These factors diminished the structural cohesion of the concrete matrix as well as the effectiveness of the fiber reinforcement when the specimens were subjected to impact loads.

Figure 9: Control Sample

Figure 10: 0.25% Sample

Figure 11: 0.50% Sample

Figure 12: 0.75% Sample

Figure 13: 1.00% Sample

The results of the 28-day drop test clearly showed the significant effect fiber content has on the impact resistance of the CHB. The overall best performing mixture was the 0.25% fiber content, as all specimens exhibited only minor damage, suggesting higher toughness and therefore a stronger resistance to impact. In addition, the results from the drop test correlate to the results from the compressive strength tests, where the control mix (0% fiber) exhibited a better performance at the later ages (14 days) and the highest compressive strength at both 7 and 28 days. Overall, the small amount of fiber used (0.25%) enhanced the impact resistance without substantially diminishing the compressive strength properties, while the addition of excessive amounts of fiber proved to be detrimental to both properties.

G. Cost Analysis

Table 12
Summary of Cost Analysis of Fiber-Reinforced CHBs

Fiber Content	Estimated Cost per CHB (₱)	% Increased	Remarks
0%	14	—	Conventional CHB
0.25%	16	14.3%	Most cost-efficient
0.50%	17	21.4%	Higher preparation cost
0.75%	19	35.71%	Reduced workability
1.00%	20	42.86%	Highest production cost

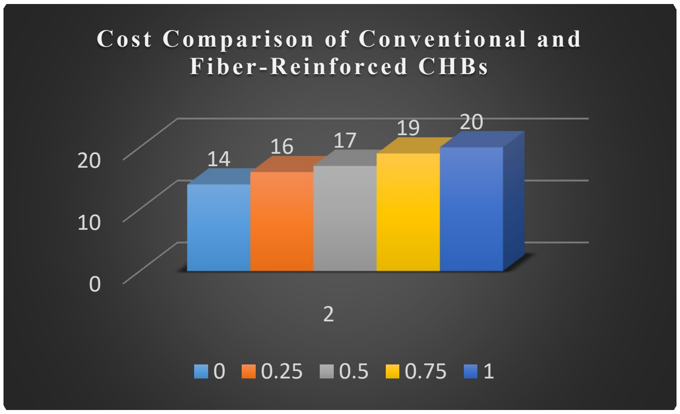


Fig.14. Cost Comparison of Conventional and Fiber-Reinforced CHBs

According to the data from the cost analysis, the addition of chemically treated PALF and Manila Hemp (Abaca) fibers increased the overall cost of manufacturing concrete hollow blocks (CHBs). The major factor causing the increase in cost was the fiber separation process, which involves cleaning and preparing the fibers for mixing (alkali treatment with 4% sodium hydroxide (NaOH)), rinsing/drying, and cutting. The higher amount of fiber content requires longer preparation time and more labor, which adds to the cost of manufacturing the CHBs Of all the mixtures tested, it was found that the CHBs produced with 0.25% fiber content had the best economic performance since they were only slightly more costly than the standard mixture but had increased compressive strength, acceptable densities, improved impact resistance, and good workability/consistency. Thus, the addition of a small amount of fiber reinforcement tends to improve the overall performance of CHBs without substantially increasing the costs of production. However, as the proportion of fiber exceeded 0.50%, the price of materials used in producing CHBs were progressively increased due to the greater quantities of fiber needed, and more procedures required to prepare those fibers at such higher percentages for CHB production. There was no improvement in mechanical performance for these higher fiber percentages, but rather the additional fiber caused reduced workability, created clusters of fiber, and developed internal voids, which had a detrimental effect on the compressive strength of the CHBs and the compactness of the sample.

Based on the findings, PALF and Abaca fibers which have been chemically treated are found to be potential sustainable reinforcement materials for non-loadbearing CHBs when used at optimum fiber proportions. Although the fibers when added to the mixture create additional cost to manufacture the CHBs, the potential environmental benefit from using agricultural residues combined with improved tensile strength of the samples may outweigh the additional costs of production when applied in actual practice.

H. Multi-Criteria Decision Analysis

Multi-Criteria Decision Analysis (MCDA) was performed to evaluate and prioritize the different mixtures of CHBs for at least five performance criteria (compressive strength, density, drop test resistance, workability, and cost) by assigning each criterion equal weights of 20% so that mechanical, physical, functional and economic properties would all receive equal weight.

Table 13
MCDA Weighted Scores and Ranking of CHB Mixtures

Mixture	Strength	Density	Drop Test	Workability	Cost	Total Score	Rank
0%	**4** (0.80)	**4** (0.80)	**3** (0.60)	**5** (1.00)	**5** (1.00)	4.20	**2**
0.25%	**5** (1.00)	**4** (0.80)	**5** (1.00)	**4** (0.80)	**4** (0.80)	4.40	**1**
0.50%	**3** (0.60)	**5** (1.00)	**3** (0.60)	**3** (0.60)	**3** (0.60)	3.40	**3**
0.75%	**2** (0.40)	**3** (0.60)	**1** (0.20)	**2** (0.40)	**2** (0.40)	2.00	**4**
1.00%	**1** (0.20)	**2** (0.40)	**1** (0.20)	**1** (0.20)	**1** (0.20)	1.20	**5**

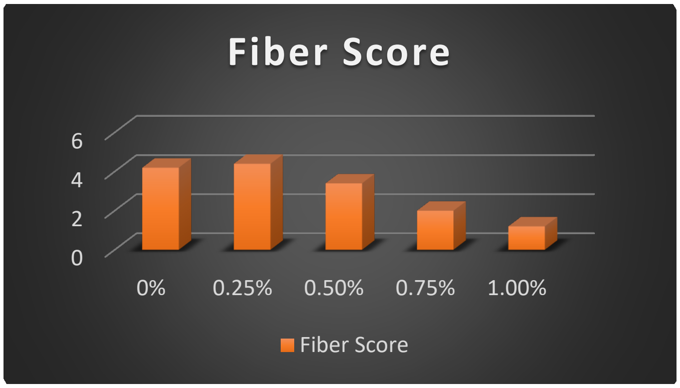


Figure 15: MCDA Total Score of CHB Mixtures

The MCDA showed the best overall performance with the fiber content of 0.25% with the data showing the highest total score of 4.40 which ranks it in first place for all evaluated mixtures. This is indicative of an optimal composite of mechanical, physical, functional and economic performance levels for the listed criteria. The control mixture, with 0% fiber, received a total score of 4.20 which is indicative of a good baseline level for performance but slightly less efficient than the fiber-enhanced mixture based on the criteria evaluated in this study.

As shown, higher percentage fiber mixtures provided decreasing performance in relation to the control and/or low percentage fiber, primarily due to the reduced overall workability and structural performance of those mixtures. While the addition of low fiber percentages may exhibit improved properties of composite behavior, when fiber percentages exceed a certain limit, deterioration of performance exceeds any further improvement of material properties from that added fiber content.

Accordingly, the results of this research indicate that an optimal mixture of 0.25% fiber provides the optimal balance of mechanical strength, durability and cost effectiveness, confirming the theory of an optimal dosage or amount of fiber beyond which the disadvantages of performance degradation exceed the advantages of any additional material benefits derived from the added fiber.

4. Summary, Conclusions and Recommendations

A. Summary

Based on the results gathered from the experimental procedures, the researchers obtained the following findings:

In light of the findings of the sieve analysis and compressive strength testing of the concrete hollow blocks (CHB), it was determined that the fine aggregates used in the study were poorly graded and excessively coarse, as indicated by a fineness modulus of 4.26. This value is significantly higher than the standard range for fine aggregates (2.3-3.1). As a result this poor particle packing, increased void content, and weak bonding between the cement paste and aggregates. Thus, all the CHB specimens, whether control specimens without fibers or specimens with fibers, could not meet the specified compressive strength requirements. Hence, it can be said that the major reason for such failure was inappropriate gradation of the fine aggregate.

The compressive strength tests revealed the significant effect of adding fiber on the compressive strength of the CHB's (Concrete Hollow Block). The mix with 0.25% of fiber content produced superior results with respect to compressive strength in comparison to the control mix. The strength of the mix containing 0.50% fiber content was acceptable but began to decrease in compressive strength; however, the addition of fiber content at 0.75% and 1.00% demonstrated a significant reduction in compressive strength due to a lack of compaction, fiber clumping, and air voids in the specimen.

The density test results reflected a gradual reduction in density with the addition of fiber content. The highest density was identified with the control mix, and the lower density was identified at the higher fiber content mixes. Thus, it can be concluded that higher fiber additions provide additional air voids in the CHB's and, therefore, less compacted CHB's. The 0.25% fiber mix provided a more homogeneous and denser structure than any of the other mixes, thus allowing it to have superior performance characteristics.

With regard to drop testing (impact resistance), testing demonstrated that the control mix (0) passed two out of the three specimens and the remaining specimen sustained minor cracking and one partial failure; therefore, it had moderate to low impact resistance and was brittle in behaviour. The 0.25% fiber mix produced the best results with respect to impact resistance, all three specimens passed with no visible damage, demonstrating enhanced resistance to cracking and improved energy dissipation due to the impact. At 0.50% fiber content, one of the three specimens passed, while the remaining specimens failed due to partial failure and separation; therefore, the results demonstrated inconsistent performance at 0.50% fiber content. For 0.75% and 1.00% fiber percent, all samples were destroyed and displayed extensive damage, including fragmentation. These results indicate that fiber addition improves impact resistance only at optimal levels, while excessive fiber content weakens the structural integrity of the CHBs.

Results of the workability assessment demonstrated a linear decrease in the ease of handling of the mixtures as the fiber content increased. The control mix exhibited very good quality of workability (smooth), whilst the mix containing 0.25% fiber was still sufficiently workable, but with an increase in stiffness compared to that of the control sample. The mixture was extremely difficult to compact with 0.50% of fiber added due to being stiff and compactable. The mixtures with 0.75% and 1.00% fiber were both very difficult to compact; however, there was also evidence of fiber clumping and an overall decrease in flowability. The decrease in workability was caused by the high water absorption capacity of the fiber material; hence, the shear friction between fiber particles and the friction between neighboring fibers/particles increased, resulting in the fibers being interlocked and thus the mixture was very difficult to work with.

PALF and Abaca fiber inclusion slightly increased production costs due to fiber preparation, treatment, and mixing processes. Nonetheless, the enhanced durability and crack resistance at optimum fiber contents imply that the materials may be economically advantageous due to decreasing maintenance and replacement costs.

Overall, the findings indicate that fiber reinforcement has both beneficial and limiting effects, depending on the proportion used.

B. Conclusions

The general objective of assessing the influence of chemically treated fibers of PALF and Abaca on performance characteristics of CHBs was successfully achieved. The impact that the inclusion of natural fibers has on mechanical and physical characteristics of concrete hollow blocks has been verified through the completion of this project. Based on data analyzed in this report, the optimum fiber content in CHB is 0.25%. This is because the best balance is achieved at this fiber content for compressive strength, durability and workability of the concrete hollow blocks because the tests showed improved impact resistance, minimal cracks and acceptable workability compared to CHB with no fiber content. At this stage, the CHBs showed increased impact strength, negligible cracking, and satisfactory workability.

It was concluded from the testing that although adding fiber does improve some characteristics of the concrete/fiber mixtures, such as resistance to cracking and the ability to absorb energy, there are adverse effects caused by adding too much fiber (0.50 to 1.00%). Higher percentages of fiber resulted in reduced compressive strength, poor workability and weakened internal structure of the concrete/fiber mixture due to excess clustering of fibers and increased voids.

Furthermore, the drop test results confirmed that fiber reinforcement is effective only when properly distributed and maintained within an optimal range. Beyond this range, the reinforcing effect of fibers is outweighed by the reduction in structural integrity.

The study concludes that chemically treated PALF and Abaca fibers are viable as sustainable reinforcement materials for non-load-bearing CHBs, particularly when used in optimal proportions.

All specific objectives of the study, including evaluation of compressive strength, determination of optimal fiber content, assessment of durability and workability, and cost analysis were successfully attained.

C. Recommendations

The results of the study have certain limitations and indicate different directive for future research.

The first future directive is for researchers to investigate smaller differences in the percent of fibers in the composite material such as 0.20%, 0.30%, and 0.40% in order to have better accuracy for the optimal mix of fibers.

Conduct preliminary trial mixes before final sample production. This helps ensure a more consistent and reliable mix for the actual specimens and reduces the chance of producing failed samples.

An additional recommendation is to use chemical additives like superplasticizers and water-reducing agents to enhance the workability of mixtures containing higher fiber content.

Another very important recommendation is to use water curing as a method of moisture-cured cement (submerged method) so that all cement particles can receive moisture through immersion. Using water curing for these samples will have some advantages such as: decreasing the number of internal voids, enhancing the bond between fiber and cement, and providing consistency in results of specimens with both water and air cured and those of surface cured ones.

Another possible study could involve comparing various mixtures of PALF and Abaca fibers rather than a constant mixture to find out the most suitable combination of materials, to identify the best fiber combination.

Testing should be carried out further for other mechanical properties as well. This would include testing for flexural strength, tensile strength, and modulus of elasticity to ensure that all aspects of the potential performance of the material are thoroughly covered.

In addition, durability tests over a period of time, such as water absorption, shrinkage, creep, and weathering behavior of fiber-reinforced CHB concrete, must be conducted to generate more data on the performance of fiber-reinforced CHBs in different environments.

Additionally, it is important to enhance mixing processes and procedures for manufacturing fiber-reinforced CHBs in order to ensure proper dispersion and avoid fiber clumping inside the concrete matrix.

In addition to that, field testing or large-scale testing must be conducted in order to verify the findings obtained from laboratory testing and determine the construction practice used by the material.

Finally, thorough economic evaluation needs to be done on the transportation and manufacturing costs of large-scale products made of fiber reinforced CHB to analyze its feasibility as a construction material.

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