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Investigation on Load-Bearing Concrete Hollow Block Reinforced with Coconut Coir Fiber

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Abstract

The aim of this study is to produce a load-bearing concrete hollow block (CHB) with pre-treated coconut fiber passing the required minimum compressive strength. The CHB was added with 1, 2 and 3% pre-treated coconut coir fibers, by weight of cement, at varying coconut fiber lengths of 3, 4.5 and 6 cm during the production. Class AA concrete mixture of 1:1.5:3 is used with a water-cement ratio (w/c) of 0.51. There were three representative samples taken at each percentage (1, 2 and 3%) of pre-treated coconut coir fibers added in every 3, 4.5 and 6 cm length and a total of 30 samples were produced for the investigation process. The compressive strengths of load-bearing CHBs were then taken using the universal testing machine and results showed that 2% coconut coir fiber of 4.5 cm fiber length is significantly different from 1 and 3% coconut coir fiber. Results revealed that CHB with 2% coconut fibers obtained the optimum compressive strength compared to the 1 and 3% CHB samples. The study concluded that coconut fiber reinforced load-bearing CHBs can be used for Type N Mortar for the general purpose of above grade applications where normal loading occurs such as reinforced interior and exterior load-bearing walls.

***Keywords**:* pre-treated coconut coir fiber, concrete hollow block, compressive strength, waste utilization

1. Introduction

The construction industry is adding several materials in the concrete mixture to improve its ductility, and reduce permeability and bleeding by utilizing different kinds of fibers such as steel, glass, synthetic and natural fibers. Natural fibers are abundantly available all over the world and the use of natural fibers from agricultural waste has been studied to improve concrete properties. Several studies are conducted using natural fiber reinforcement for the production of mortar (sand cement) and these include fibers from coconut, bamboo, leaf and fruit (Paramasivam *et al.*, 1984; Asasutjarit *et al.*, 2007). As a matter of fact, the concrete is reinforced with natural fibers such as coir, sisal and jute in many countries (Agrawal *et al*., 2014).

The study of Sera *et al.* (1990) revealed that adding fibers prevents the development of cracks in the concrete material and increase its ductility, which also proved that adding fiber reduces its permeability and bleeding. Moreover, addition of fiber increases the resistance of the material against fracture when stressed. However, coconut fiber, one of the toughest natural fibers (Waifelate and Abiola, 2008), is not commonly used in the construction industry but only in other domestic applications such as floor mats, doormats, brushes and ropes.

Ali (2011) listed several advantages of using coconut fibers. They are resistant to fungi, rot, moth, moisture and dampness; give an excellent insulation against temperature and sound; non-combustible, tough and durable, resilient, flame-retardant, totally static-free and easy to clean. Coconut fibers return to shape after constant use. Adding fibers to structural materials, such as concrete, to control plastic shrinkage cracking, drying shrinkage cracking and lower the permeability is pre-owned. Generally, different types of fibers are used in construction industries such as steel, glass and organic fibers (Jose *et al.*, 2017).

According to Waifielate and Abiola (2008), the main constituents of coconut fiber are cellulose, hemicellulose and lignin. They added that coconut fiber has the highest percentage, by volume of lignin, which makes the fiber very tough and stiffer compared to other natural fiber. The lignin content influences the structure, properties, flexibility, hydrolysis rate and with high lignin content, it appears to be finer and also more flexible. A study of Sivaraja (2010) applied coir fibers as concrete composite and used a length of 50 mm coir fiber and two-volume factions of 0.5 and 1% content fiber. It was observed that the addition of fibers reduced the workability and the mechanical strength properties improve at 10 to 20% range.

In this research, the pre-treated coconut fiber was investigated in the production of concrete hollow blocks at 0 (control mix), 1, 2 and 3% additions, by weight of cement, at a specified design mixture of cement, sand, aggregate (choker), water-cement ratio and pre-treated coconut coir fiber lengths of 1:1.5:3:0.51 and 3, 4.5 and 6 cm, respectively.

2. Methodology

2.1 Coconut Fiber

The coconut fiber was collected from a seller in Naawan, Misamis Oriental, Philippines. It underwent a stripping process with a decorticator as shown in Figure 1. Decorticator is a machine that removes the coconut husk from which coconut coir was obtained, and separates most of the coco peat from the fibers. Fiber lengths were measured using a conventional ruler at 3, 4.5 and 6 cm lengths, respectively. The fiber did not undergo any treatment using chemical solutions since this study required the fiber to be purely natural.

Figure 1. Physical appearance of coconut fiber

2.2 Pre-treatment of Fiber

The study of Asasutjarit *et al.* (2007) shows that the pre-treated coconut fiber gives a better result than the raw fiber used directly in the cementitious mixture. The fiber was then treated following the boiling method as shown in Figure 2. The tap water was used for boiling where the fiber experienced continuous boiling for two hours. It then went through drying through solar radiation.

2.3 Washing and Sieving of Aggregates

The aggregates were washed to remove the soil and impurities. The sand and 3/8” choker aggregates were also washed and dried under the sunlight. Dried aggregates were sieved according to the designed aggregate size and the sand used in this study passed the 4-mm sieve. The choker passed the 3/8” sieve and retained in the 4-mm sieve.

Figure 2. Boiling of coconut fiber for two hours

2.4 Design Mixture of the CHB

The dimension of the CHB had a width of 6”, a height of 8” and a length of 16” as shown in Figure 3. The web and face shell thicknesses were 1.25” and 1.5”, respectively, as shown in Figure 4. Type I ordinary Portland cement was also used in this study as per American Society for Testing and Materials (ASTM) C150 (2019) standards.

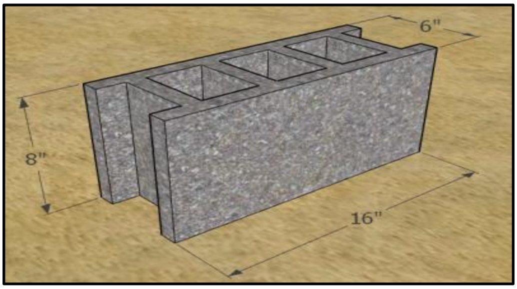

Figure 3. Dimension of concrete hollow block

Figure 4 illustrates the top dimensions of the CHB. The web of the CHB for 3” length was 1.25” thick, which conforms to the requirements of ASTM C90-70 (2010) standard. The face shell for 16” length is 1.50” thick which conforms also to the same standard. The overall net area of the CHB is 0.041 m^2.

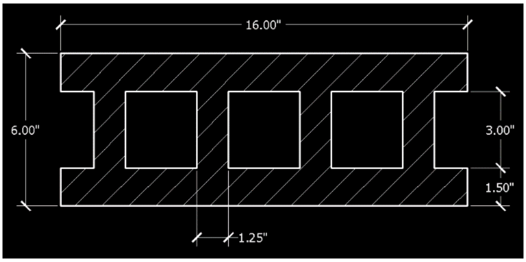

Figure 4. Top view of concrete hollow block

In Table 1, three representative samples were cast at each percentage – 1, 2 and 3% at three different lengths of 3, 4.5 and 6 cm of pre-treated coconut fibers. Additionally, three separate samples are cast also for the 0% pre-treated coconut fiber: the control mix for a total of 30-representative CHB samples.

Table 1. Production of CHBs using different percentages of pre-treated coconut fiber

Description	No. of Samples
0% Pre-Treated Coconut Fiber (Control Mix)	3
1% Pre-Treated Coconut Fiber, 3 cm	3
2% Pre-Treated Coconut Fiber, 3 cm	3
3% Pre-Treated Coconut Fiber, 3 cm	3
1% Pre-Treated Coconut Fiber, 4.5 cm	3
2% Pre-Treated Coconut Fiber, 4.5 cm	3
3% Pre-Treated Coconut Fiber, 4.5 cm	3
1% Pre-Treated Coconut Fiber, 6 cm	3
2% Pre-Treated Coconut Fiber, 6 cm	3
3% Pre-Treated Coconut Fiber, 6 cm	3
Total	30

2.5 Proportioning of CHB Concrete Mixture

The CHB concrete mixture was obtained using Class AA concrete mix of 1:1.5:3 for cement, sand and choker using a water-cement ratio (w/c) of 0.51. The proportioning of CHB component materials was calculated and tabulated in Table 2.

Table 2. Component materials (by weight of cement) used in CHB concrete mix

% Coconut Fiber	Fiber Length (cm)	No. of Samples	W/C Ratio	Water (kg)	Fiber (kg)	Cement (kg)	Sand (kg)	Choker (kg)
1%	3.0	3	0.51	6.20	0.1216	12.16	18.24	36.48
1%	4.5	3	0.51	6.20	0.1216	12.16	18.24	36.48
1%	6.0	3	0.51	6.20	0.1216	12.16	18.24	36.48
2%	3.0	3	0.51	6.20	0.2432	12.16	18.24	36.48
2%	4.5	3	0.51	6.20	0.2432	12.16	18.24	36.48
2%	6.0	3	0.51	6.20	0.2432	12.16	18.24	36.48
3%	3.0	3	0.51	6.20	0.3648	12.16	18.24	36.48
3%	4.5	3	0.51	6.20	0.3648	12.16	18.24	36.48
3%	6.0	3	0.51	6.20	0.3648	12.16	18.24	36.48

2.6 Production of CHB

In the production of CHBs, a suitable place and shaded area, where one can work without any distraction, was sought at Upper Balulang, Cagayan de Oro City. Prior to mixing, the coconut fiber was stripped in order to reduce the tendencies of tying together. First, cement and sand were mixed manually until the mixture appears homogeneous. Second, the choker was added to step one until the mixture was even and uniform. Third, the pre-treated coconut fiber at the exact percentage (0, 1, 2 and 3%) and exact lengths (3, 4.5 and 6 cm) were added to step two and then mixed together until uniformity of the mixture was apparent. Fourth, the pre-determined amount of clean water was then poured into the mixture of the component materials. Fifth, mixing of the water with the component materials was done using hand trowels. Sixth, the wet mix was then tested for workability (slump test) in accordance with ASTM C143 (2015). Seventh, the concrete mix was then poured into molds. An amount of the mix about one-third of the height of the mold was first poured and then slightly compacted using 1” x 1” tamping rod. This was then followed by the filling the mold with an additional concrete until two-third and full volume and slightly compacting it with 1” x 1” tamping rod to reduce and remove the air voids. Finally, the CHB samples were unmolded in a plain surface and stored in a room under a normal condition where they were cured for 28 days by sprinkling with water thrice a day.

2.7 Curing of CHB Samples

The purpose of curing is to protect the concrete hollow block from the loss of moisture. Curing helps the material to grow in strength and diminish cracking. CHBs were shaded from sunlight in order to be effectively cured. The curing process started after unmolding the CHB sample with a curing period of 28 days. The CHB samples then were watered three times a day.

2.8 Testing of CHB Samples

Each CHB specimen underwent a compressive strength testing using the Universal Testing Machine (UTM) as per the ASTM C140 (2018). The average minimum compressive strength of a load-bearing concrete hollow block is 10.3 MPa or 1,493 pounds per square inch (psi) according to the National Structural Code of the Philippines [NSCP] of the Association of Structural Engineers of the Philippines (2015).

2.9 Data Analysis

Results of the compressive strength testing were graphed for 28-day age of curing. The increase or decrease of compressive strengths of the CHB was presented in percentages and compared to the control mix. Variations of compressive strengths at different fiber lengths were also compared in terms of percentages. To identify the significance in the variation in compressive strengths, the analysis of variance (ANOVA) was conducted.

3. Results and Discussion

3.1 Compressive Strength Results

The UTM recorded the compressive strengths applied, with a unit of kiloNewton (kN) and the pressure with a unit of pounds psi. The concrete mix proportions of CHBs using the Class AA concrete mixture, with percentages of pre-treated coconut fiber (by weight of cement) passing the minimum required compressive strength of 1,493 psi (10.3 MPa) for the masonry of hollow load-bearing units, are presented in Table 3.

Table 3. CHBs concrete mix proportions passing the minimum required compressive strength after 28-day curing

% Coconut Fiber	Fiber Length (cm)	W/C Ratio	Water (kg)	Fiber (kg)	Cement (kg)	Sand (kg)	Choker (kg)	Actual Compressive Strength (psi)
1%	6.0	0.51	6.20	0.1216	12.16	18.24	36.48	1,617
2%	4.5	0.51	6.20	0.2432	12.16	18.24	36.48	1,720

Table 4 below shows the actual compressive strengths, adding 1 and 2% pre-treated coconut fiber in CHB mix, superseding the minimum required compressive strength using the 6 and 4.5 cm fiber lengths, respectively. Table 4 also indicates the type of mortars to be used in the actual application.

Table 4. CHBs passing minimum required compressive strength after 28-day curing

Description	Actual Compressive Strength		Ave. Compressive Strength	Type of Mortar/Application
	psi	MPa	(psi)	
Control	1,493	10.3	1,493	Type N/General purpose applications above grade where normal loading occurs such as reinforced interior and exterior load-bearing walls.
2% Pre-Treated Coconut Fiber, 4.5-cm Length	1,785 1,935 1,440	12.32 13.35 9.94	1,720	Type N/General purpose applications above grade where normal loading occurs such as reinforced interior and exterior load-bearing walls.
1% Pre-Treated Coconut Fiber, 6-cm Length	1,783 1,506 1,562	12.30 10.39 10.78	1,617	Type N/General purpose applications above grade where normal loading occurs such as reinforced interior and exterior load-bearing walls.

Figures 5, 6 and 7 show the graphs of actual compressive strengths of CHBs adding 1, 2 and 3% pre-treated coconut fibers using 3, 4.5 and 6 cm fiber lengths.

After 28 days of curing, the average compressive strengths of CHBs reached 1297, 1720 and 1617 psi for 3 cm length/2% pre-treated coconut fiber, 4.5 cm length/2% pre-treated coconut fiber and 6 cm length/1% pre-treated coconut fiber additions, respectively. A 13.1% (196 psi) decrease in compressive strength is observed against the 1493 psi of the control mix for the 3 cm length/2% pre-treated coconut fiber. 15.2% (227 psi) and 8.3% (124 psi) increases in compressive strengths are noticed in 4.5 cm length/2% pre-treated coconut fiber and 6 cm length/1% pre-treated coconut fiber.

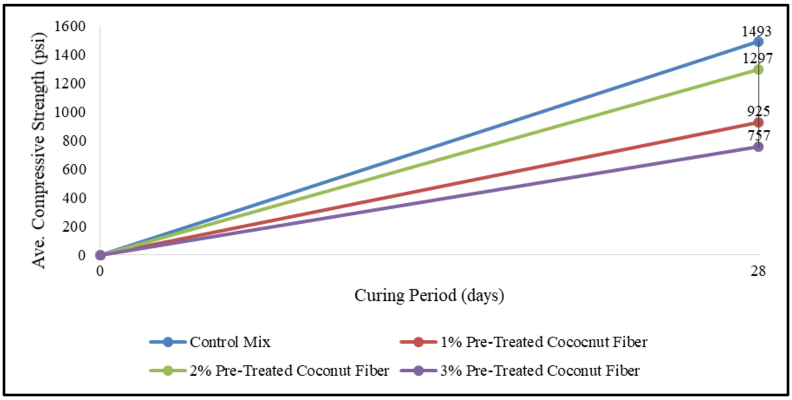

Figure 5. Average compressive strengths of CHB with 3 cm length coconut fiber

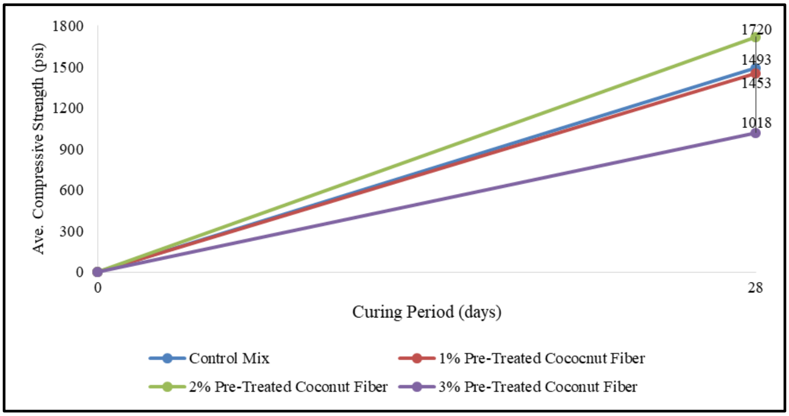

Figure 6. Average compressive strengths of CHB with 4.5 cm length coconut fiber

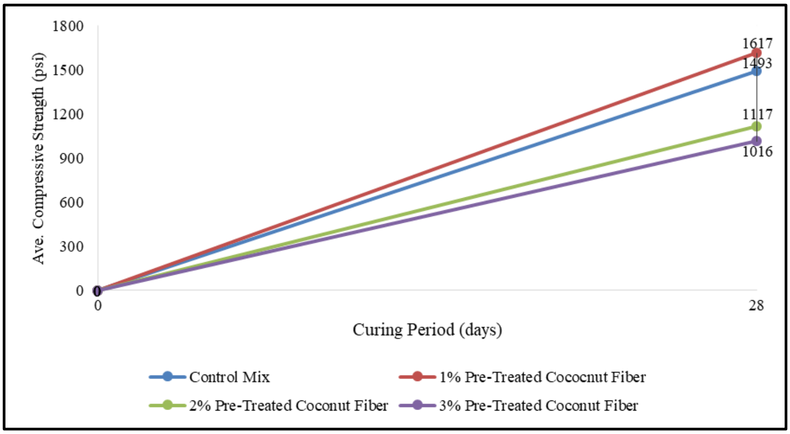

Figure 7. Average compressive strengths of CHB with 6 cm length coconut fiber

3.2 Analysis of Variance (ANOVA)

The single factor ANOVA or one-way ANOVA determines if the average compressive strength results have a statistically significant difference from each other. To know if there is a significant difference within the results, the actual F-value, critical F-value and P-value must be observed. If the actual F-value is greater than the critical F-value and the P-value is less than 0.05, it can be concluded that there is a significant difference within the results. A Post hoc *t*-Test is then conducted when a significant difference between sample means is established in the one-way ANOVA test. Moreover, H_o is a null hypothesis indicating there is no significant difference between sample means.

Table 5 shows the average compressive strengths of CHB specimen for 1, 2 and 3% additions of coconut coir fibers for 3, 4.5 and 6 cm lengths. Based on the table, 2% coconut coir fiber of 4.5 cm length and 1% coconut coir fiber of 6 cm length, with average compressive strengths of 1720 and 1617 psi, exceeded the 1493 psi compressive strength of the control mix by 15.2 and 8.3%, respectively.

Table 5. Compressive strengths for the 3, 4.5 and 6 cm lengths coconut coir fiber

Specimen	3 cm			4.5 cm			6 cm		
% Coconut Coir Fiber	1%	2%	3%	1%	2%	3%	1%	2%	3%
1	908	690	678	1109	1785	1144	1783	1079	1033
2	828	1617	848	1351	1935	1282	1506	1361	1147
3	1038	1585	745	1898	1440	629	1562	910	868
Average	925	1297	757	1453	1720	1018	1617	1117	1016

Table 6 shows the ANOVA of CHB specimen for 1, 2 and 3% additions of coconut coir fibers for 3, 4.5 and 6 cm lengths. F statistic is the value obtained to determine if the means between samples are significantly different. If the calculated F is larger than the F statistic (F_{crit}), there is a significant difference between CHB samples. In other words, the calculated F is a measure of significance between samples. However, the calculated F must be used in combination with the probability value (P-value) to evaluate the overall results, i.e., the calculated F value should always be used together with the P-value to determine whether the sample results are significant enough to reject the null hypothesis. Based on the table, the actual F-values of 2.33 and 3.26 for 3 and 4 cm coconut coir fiber lengths are less than the critical F-value of 5.143. On the other hand, P-values of 0.178 and 0.110 for 3 and 4 cm coconut coir fiber lengths are greater than 0.05. These results only indicate that there is no significant difference between sample means, i.e., the null hypothesis H_o is not rejected. Thus, no Post hoc *t*-Test is conducted. In addition, the 6 cm length coconut coir fiber has an F-value of 10.02, which is greater than the critical F-value of 5.143, and a P-value of 0.012 which is less than 0.05. This implies that there is a significant difference between sample means. Hence, the null hypothesis H_o is rejected and Post hoc *t*-Test must be conducted as shown in Table 7.

Table 6. Sources of variation between and within groups

Description	SS	df	MS	F	P-value	F_{crit}
3 cm Length						
Between Groups	458953	2	229476	2.33	0.178	5.143
Within Groups	590925	6	98488			
4.5 cm Length						
Between Groups	752449	2	376224	3.26	0.110	5.143
Within Groups	692507	6	115418			
6 cm Length						
Between Groups	621668	2	310834	10.02	0.012	5.143
Within Groups	186085	6	31014			

Table 7 shows the Post hoc *t*-Test, comparing CHB specimen at 1, 2 and 3% of 6 cm length coconut coir fiber and evaluating the significance between sample means. For 1% vs. 2% pre-treated coconut coir fiber, P(T<=t) two-tail of 0.032918 is less than 0.05, i.e., 1% pre-treated coconut fiber is significantly different from 2% pre-treated coconut fiber. Thus, there is a significant difference between sample means.

For 1% vs. 3% pre-treated coconut coir fiber, P(T<=t) two-tail of 0.006825 is less than 0.05, i.e., 1% pre-treated coconut fiber is significantly different from 3% pre-treated coconut fiber. Therefore, there is a significant difference between sample means.

In 2% vs. 3% pre-treated coconut coir fiber, P(T<=t) two-tail of 0.550171 is greater than 0.05, i.e., 2% pre-treated coconut fiber is not significantly different from 3% pre-treated coconut fiber. Hence, there is no significant difference between sample means.

Table 7. Post hoc *t*-Test of CHBs at 1, 2 and 3% of 6 cm length coconut coir fiber

Description	1% vs. 2%		1% vs. 3%		2% vs. 3%	
Mean	1617	1116.67	1617	1016	1116.67	1016
Variance	21451	51914.3	21451	19677	51914.33	19677
Observations	3	3	3	3	3	3
Pooled Variance	36682.67		20564		35795.67	
Hypo. Mean Diff.	0		0		0	
df	4		4		4	
t Stat	3.199445		5.132941		0.651653	
P(T≤t) One-Tail	0.016459		0.003412		0.275086	
t Critical One-Tail	2.131847		2.131847		2.131847	
P(T≤t) Two-Tail	0.032918		0.006825		0.550171	
t Critical Two-Tail	2.776445		2.776445		2.776445	

4. Conclusion and Recommendation

The addition of coconut coir fiber to CHBs can increase the compressive strength of CHB. It was observed that the addition of 1% coconut coir fiber using a 6 cm length was able to attain a compressive strength beyond the control mix design.

Having attained a compressive strength more than 1,493 psi (10.3 MPa) of the NSCP, the study concluded that coconut fiber-reinforced load-bearing CHBs can be used for Type N Mortar for the general purpose above grade applications, where normal loading occurs such as reinforced interior and exterior load-bearing walls.

It is recommended to consider the production of the optimum length of 6 cm optimum length pre-treated coconut coir fiber to make this material readily available for CHB production. This will lead to another entrepreneurial supplier in producing CHB with reinforced coconut coir fiber.

5. Acknowledgement

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6. References

American Society for Testing and Materials (ASTM) C90-70. (2010). Standard specification for loadbearing concrete masonry units. Washington D.C: American Society for Testing and Materials.

American Society for Testing and Materials (ASTM) C143. (2015). Standard specification for slump test for Portland cement. West Conshohocken, PA: ASTM International.

American Society for Testing and Materials (ASTM) C140. (2018). Standard test methods for sampling and testing concrete masonry units and related units. West Conshohocken, PA: ASTM International.

American Society for Testing and Materials (ASTM) C150. (2019). Standard specification for Portland cement type I. West Conshohocken, PA: ASTM International.

Agrawal, R.A., Dhase, S.S., & Agrawal, K.S. (2014). Coconut fiber in concrete to enhance its strength and making lightweight concrete. International Journal of Engineering Research and Development, 9(8), 64-67.

Ali, M. (2011). Coconut Fibre: A versatile material and its applications in engineering. Journal of Civil Engineering and Construction Technology, 2(9), 189-197.

Asasutjarit, C., Hirunlabh, J., Khedari, J., Charoenvai, S., Zeghmati, B., & Cheul Shin, U. (2007). Development of coconut coir-based lightweight cement board. Construction and Building Materials, 2(21), 277-288.

Association of Structural Engineers of the Philippines (ASEP). (2015). National Structural Code of the Philippines (7th Eds., Vol. 1). Quezon City, Philippines: Association of Structural Engineers of the Philippines, Inc.

Jose, S., Mishra, Leena, Basu, G., & Samanta, A.K. (2017). Study on reuse of coconut fiber chemical retting bath. Part II – recovery and characterization of lignin. Journal of Natural Fibers, 4(14), 510-518. https://doi.org/10.1080/15440478.2016.1212772

Paramasivam, P., Nathan, G.K., & Das Gupta, N.C. (1984). Coconut fiber reinforced corrugated slabs. International Journal of Cement Composites and Lightweight Concrete, 6(1), 19-27. https://doi.org/10.1016/0262-5075(84)90056-3

Sera, E., Robles, L., & Pama, R. (1990). Natural Fibers as Reinforcement. Journal of Ferrocement, 20(2), 109-205.

Sivaraja, M. (2010). Application of coir fibres as concrete composites for disaster prone structures (Report). Central Institute of Coir Technology, Banglore, India.

Waifielate, A., & Abiola, B. (2008). Mechanical property evaluation of coconut fiber (Thesis). Department of Mechanical Engineering, Blekinge Institute of Technology, Karlskrona, Sweden.