Coconut (*Cocos nucifera* L.) Waste as Partial Coarse Aggregate Replacement for Concrete Hollow Blocks

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Abstract –*Concrete hollow block is a vital component in construction industry because of its affordability, strength, and convenience. However, the excavation of conventional coarse aggregates devastates the surroundings with massive contributions to environmental pollution. Thus, a viable replacement using agricultural wastes as an aggregate to concrete hollow blocks could lessen its impact to the environment. The research aimed to identify the potentiality of coconut shells and coir fiber as partial coarse aggregate replacement to concrete hollow blocks in terms of compressive strength, water absorption rate, workability, and economic value. A nominal mix design was applied by the researchers in the production of cylindrical specimens having two curing days, 14 and 28, with proportions amounting to 0 % (conventional), 15%, 30% and 45% coconut shell and coir fiber. Results showed that all the cylindrical specimens passed the American Society for Testing and Materials (ASTM) standards specifically in non-load bearing concrete. However, the increasing coconut waste proportions increased the water absorption rate while decreasing the compressive strength and workability. In addition, total cost of production was reduced when coconut shells and coir fiber were used compared to the expenses required in the conventional concrete. The findings prove to be useful in both construction and agricultural industries by proving the viability of an agricultural waste, coconut shell and coir fiber, as partial coarse aggregate replacement in making concrete hollow blocks.*

Keywords –*aggregate, ASTM, coconut shell, coir fiber, concrete hollow blocks*

INTRODUCTION

Concrete hollow block (CHB) is one of the most widely used walling material in building and infrastructure. It is formed from a mixture of Portland cement, aggregate, and water [1] which undergoes hydration where it hardens to form rectangular solid blocks. However, the excavation of conventional coarse aggregates devastates the surroundings with massive contributions to environmental pollution [2].

Hence, finding a viable material as a substitute to conventional aggregate has been a mission of the construction industry. A potential source of this is agricultural waste which can be treated by recycling disposed materials [3]. One possible source material is the coconut.

There are over 92 countries around the world that produce coconut products and one of its top producers is the Philippines [4]. Around 3.26 million hectares of the country's land area are used for its production [5] with an average of more than 15 million tons of coconut products being yielded every year [4]. However, the immense coconut production also increased the agricultural waste. In fact, one of the major agricultural wastes from the Philippines comes from the coconut: the coconut shell and the coconut coir fiber [6].

Coconut shell (CS), the hardest part of the coconut which is located in between its flesh and husk, is an organic substance that has the capability for long standing use due to its toughness and abrasion resistant properties. On the other hand, coir fiber (CF) are natural fibers plucked out from the coconut husk. It is a fibrous material which is located amongst the interior and exterior part of the coconut shells[7].

A large amount of coconut waste is being produced yearly; thus, the potential to utilize these as a coarse aggregate substitute in a concrete mixture would be of significant help to reduce the country's agricultural waste. It is also proven that using wastes will minimizeconcrete expenses aside from the need to use natural aggregates [8].

Several factors affect the overall quality of concrete. These factors, to name a few, include workability which is measured by slump height, compressibility, and water absorption, length of curing, and cost analysis.Concrete slump height is used to measure the workability of prepared concrete mix before being casted into desired dimensions. Poor slump height affects the strength property of concrete[9].Another factor is compressive strength. Compressive strength is the maximum compressive load that a concrete can carry at a given cross sectional area[10]. Materials for aggregate should be able to contribute to at least 25 MPa, the compressive strength for conventional concrete[11]. Also, water absorption should be considered. Water absorption of aggregates affects the cohesive property and workability of concrete [12]. Concrete with aggregate proportions having high water absorption must be avoided as it affects the quality of concrete [13]. In addition to previously mentioned factors, the length of concrete curing should also be considered. Longer curing time, 14 to 28 days, have been identified to significantly improve strength conditions in cements [14]. And lastly, the cost of production of concrete. The addition of alternative aggregates lessens the cost of production and as well as effectively utilizing materials considered as garbage and ease the depletion of natural resources[15],[16].

Previous study has utilized coconut wastes specifically CS for CHB [17]. It focused on whether the CHB with CS will pass the pre-established American Society for Testing and Materials (ASTM) standards or not and compared the cost difference between the concrete mix with CS and the conventional concrete mix. However, the mentioned study hasshown inconsistencies and the usage of different variables likemix designs, proportions, procedures, materials, and effectiveness indicators.In comparison to this research, both CS and CF were used as partial coarse aggregate replacement for CHB.

Theutilization of coconut shell and coir fiber will not only lessen the accumulation of agricultural waste like but also offer an alternative material for building industry while still attaining standards in construction.

OBJECTIVES OF THE STUDY

The study generally aimed to test the potential of using coconut shells and coir fiber (CSF) as partial replacement to coarse aggregate for concrete hollow blocks. Specifically, the research aimed to investigate the: (i) effects of different mix proportions of CSF to the concrete specimen in terms of effectiveness indicators such as workability by slump height (mm/inches), compressive strength (megapascals/psi), and water absorption (percentage); (ii) effect of curing days in compressive strength; (iii) effect of different mix proportions and length of curing days on slump height, compressive strength, and water absorption; and (iv) cost comparison between the CSF concrete specimen and the conventional concrete mix.

MATERIALS AND METHODS

Research Design

ASTM and nominal mix design procedures and standards were followed throughout the experiment. A series of concrete specimen with aggregate-coconut waste mix proportions of 0% (conventional), 15%, 30% and 45% were employed. Each proportion consisted of equal amounts of coconut shell and coir fiber per unit of volume. The concrete specimens were cured for 14 and 28 days before testing for its compressive strength and water absorption. The economic value of each mix proportions was also determined through cost analysis.

Materials

Coconut waste

Coconut shells were prepared by scraping off any remaining coconut meats, washing with warm water then sun-dry and crushing for about ¾ inch per piece.

The coir fibers were prepared by soaking in warm water for 30 minutes then sun-dried to remove its moisture content. The fibers were then cut to lengths of 50-70 mm.

Cement

Portland Type 1 hydraulic cement was utilized in the study conforming to the nominal mix design proportions.

Water

Tap water free from oils, acids and alkaline were used in the experiment.

Coarse Aggregates

Gravel is the conventional coarse aggregate that was used in the study.

Fine Aggregates

Commercial ordinary, sieved sand available locally was used in the study.

Instruments

Several 6 x 12 inches' cylindrical moulds were made from PVC pipes in accordance with*ASTM C-31: Standard Practice for Making and Curing Concrete Specimen* for compressive strength tests and water absorption test.

A slump cone with a 100 mm top, 200 mm base and 300 mm height were used to test for workability in accordance with ASTM C-143: Standard Test Method for Slump of Hydraulic-Cement Concrete. A 5/8-inch metal rod was also used in the procedure in accordance with the ASTM C-31 and ASTM 143.

Data Gathering Procedures

Proportioning

Based on the Nominal Mix Design, a ratio of 1:2:4 was used for the quantity of cement, sand, and coarse aggregates with water-cement ration of 0.55. All proportions were measured by volume.

Mixing

Thorough manual mixing was done by the researchers to integrate the materials evenly.

Slump Test

The slump test was performed after mixing the concrete mixture to measure the degree of consistency and extent of workability of the concrete mixture [18]. The slump cone was filled with the concrete mix, then the cone was removed vertically. After that, displacement of the original center to the top of the cone was recorded.

Casting and curing of concrete specimen

After mixing and slump testing, the concrete mix was poured into a 6 x 12-inch cylindrical mold. The specimens were then cured for 14 and 28 days in an enclosed container filled with water to avoid evaporation.

Compressive strength test

After curing, the specimens were taken out the water until the surface dried. Then, compressive strength was done using the Universal Testing Machine, increasing loads were applied on the specimen until failure.

Water absorption test

Drying of the specimen was done after curing, then weighed for its initial weight. The specimens were submerged in water for 24 hours. It was weighed again after immersion for its final weight.

Cost analysis

Percent difference was used to compute the difference between the total cost of production between conventional concrete and concrete with aggregates.

RESULTS AND DISCUSSION

Slump Test Results

Table 1 C-45 attained the highest slump of 90 mm while C-0 got the lowest slump height of 50 mm. Concrete mixtures with coconut shell and coir fiber passed the slump requirements measured in terms of vertical displacement.

Table 1. Slump Test Results

Speci-men	Trial/Slump height (mm) 1	2	3	Mean (mm)	Remarks
C-0	50	55	57	54	Passed
C-15	67	70	70	69	Passed
C-30	75	80	77	77.33	Passed
C-45	85	90	90	88.33	Passed

- 50 mm ≤ Average (mm) ≤ 100 mm = "Passed
- Average (mm) < 50 mm, Average (mm) > 100 mm = "Failed"

Slump test is done to test the workability and the consistency of the concrete mixture. Greater slump will cause the aggregates to settle at the bottom as the concrete solidifies. This could cause a non-uniform composition that can make the concrete collapsed upon addition of load [19]. The standard value for the slump test according to the ASTM-C143 is 2-4 inches or 50mm to 100mm. In this case, all the concrete mixtures passed the minimum given requirement including mixtures with coconut shell and coir fiber but in moderate workability.

The concrete mix and average slump height exhibit a positive relationship. With slump height being an inversely interpreted value of workability, this means that as the coconut waste proportions increase, the workability of concrete decreases. This result occurs because compared to the usual and normal aggregates, coconut shell has higher water absorption [20]. Moreover, a plausible explanation for such behavior is the particle shape of the coconut shell [21].

Table 2. Compressive Test Result of 14-day Old Concrete Cylinder

Mark	Trial	Compressive Strength MPa	Compressive Strength Psi	Specified Compressive Strength MPa	Specified Compressive Strength Psi	Remark
C-0	1	10.809	1,567.7	4.14	600.00	Passed
	2	8.001	1,160.4	4.14	600.00	Passed
	3	8.047	1,167.1	4.14	600.00	Passed
C-15	1	6.756	979.9	4.14	600.00	Passed
	2	9.989	1,448.8	4.14	600.00	Passed
	3	7.769	1,126.8	4.14	600.00	Passed
C-30	1	8.001	1,160.4	4.14	600.00	Passed
	2	7.634	1,107.2	4.14	600.00	Passed
	3	7.214	1,046.3	4.14	600.00	Passed
C-45	1	6.937	1,006.1	4.14	600.00	Passed
	2	6.237	904.6	4.14	600.00	Passed
	3	8.534	1,237.8	4.14	600.00	Passed

- Compressive strength (psi) > Specified Compressive strength (psi) = "Passed"
- Compressive strength (psi) < Specified Compressive strength (psi) = "Failed"

Table 2 shows the compressive strength test results of concrete cylinders cured for 14 days. Concrete cylinder marked C-0 attained the highest computed compression with bearing maximum load of 196,134 N and a compressive strengthof 10.809 MPa or 1,567.7 psi. On the other hand, C-45 concrete specimen tested the lowest maximum load with 117,660 N resulting to 6.237 MPa or 904.6 psi.

All tested concrete specimen passed the specified compressive strength of non-load bearing concrete set by ASTM equal to 4.14 MPa or 600 psi exceeded it by at least 304.6 psi and as much as 848.8 psi.

For 14-day old concrete specimen, the average compressive strength increased by 116.4% from 600 psi to 1,298.4 (C-0) as compared to the specified standards. The 15% coarse aggregate replacement resulted to 97.53% increase in average compressive strength. In the case of C-30, the average compressive strength was 84.1% greater than the 600 psi standard. Lastly, a 74.9% increase was observed in C-45 in relation to the specified compressive strength set by ASTM.

In a nutshell, the average compressive strength drastically decreases as the percent share of coconut waste increases.Average compressive strength drastically decreases as the percent share of coconut waste increases.

Table 3. Compressive Test Result of 28-day Old Concrete Cylinder

Mark	Trial	Compressive Strength		Specified Compressive Strength		Remark
		MPa	Psi	MPa	Psi	
C-0	1	10.967	1,590.6	4.14	600.00	Passed
	2	13.689	1,985.4	4.14	600.00	Passed
	3	9.990	1,448.9	4.14	600.00	Passed
C-15	1	9.355	1,356.8	4.14	600.00	Passed
	2	10.544	1,529.2	4.14	600.00	Passed
	3	8.879	1,287.8	4.14	600.00	Passed
C-30	1	7.796	1,130.7	4.14	600.00	Passed
	2	7.776	1,127.8	4.14	600.00	Passed
	3	7.276	1,055.3	4.14	600.00	Passed
C-45	1	7.016	1,017.6	4.14	600.00	Passed
	2	8.001	1,160.4	4.14	600.00	Passed
	3	7.119	1,032.5	4.14	600.00	Passed

- Compressive strength (psi) > Specified Compressive strength (psi) = "Passed"
- Compressive strength (psi) < Specified Compressive strength (psi) = "Failed"

Table 3 presents the breakdown of compressive test results of 28-day old concrete cylinder. C-0 obtained the highest computed compression withstanding a maximum load of 254,974 N resulting to a compressive strength of 13.689 MPa or 1,985.4 psi. On the contrary, C-45 attained the lowest maximum load with bearing maximum load capacity of127,487 N and a compressive strength of 7.119 MPa or 1,032.5 psi.

The tested specimens passed the specified compressive strength of non-load bearing concrete equal to 4.14 MPa or 600 psi as established by ASTM. It is notable that the hardened mixture incorporated with coconut shell and coir fiber exceeded the said targeted compressive strength by at least 417.6 psi and as much as 929.2 psi.

For 28-day old concrete specimen, the average compressive strength increases by 179.2% from 600 psi to 1,074.7 (C-0) as compared to the specified standards.

The 15% coarse aggregate replacement resulted to 131.9% increase in average compressive strength. In the case of C-30, the average compressive strength was 84.1% greater than the 600psi standard. Lastly, a 78.4% increase was observed in C-45 in relation to the specified compressive strength set by ASTM. These results show that average compressive strength drastically decreases as the percent share of coconut waste increases.

The result of the compressive test showed similar trend with previous studies using palm oil shell [22] and cow dung and rice husk ash [23]. These studies reported improved compressive strength after 14 curing days.

All the concrete specimens incorporated with coir fiber and coconut shells passed the ASTM standards for non-load bearing concrete hollow blocks. Thus, the used of coconut waste as a partial replacement for coarse aggregate is viable especially in building walls, partitions, fences, and dividers.

Generally, compressive strength is dependent on the particle tensile strength and matrix strength of a lightweight aggregate[24]. Also, the compatibility of cement and aggregate are needed to put focus on aside from the water-cement ratio. The decreasing compressive strength occurred because of the cement and aggregate compatibility [25].

Water Absorption Test Results

Table 4 shows the results of water absorption test which includes the percent absorption and density of hardened concrete. Specimen C-0 (0.72%) has the least percent absorption after immersion compared to concrete specimens mixed with coconut waste. On the other hand, C-45 absorbed the most water with 1.47% difference. The coconut waste proportion and water absorption rate exhibit a positive relationship. This means that as the share of the coconut waste in the concrete mix increases, the rate of water absorption also increases.

Table 4. Absorption Test Results of Cylindrical Specimen

Mark	Absorption		Difference (%)
	Oven-dried Weight (g)	After immersion (g)	
C-0	11,120	11,200	0.72
C-15	10,810	10,910	0.93
C-30	10,610	10,740	1.23
C-45	10,050	10,200	1.47

High water absorption in concrete will affect concrete performance leading to lowerconcrete strength [26]. Given the highest water absorption of 1.47% for C-45, the computed water absorption values of the study are lower than 10 % which is the accepted value for most construction materials [27]. All the concrete specimens passed the required percent absorption set by ASTM for non-load bearing concrete hollow blocks (not exceeding 2%). Therefore, the concretes produced with partial aggregate substitute of coconut shells and coir fibers are viable for applications.

Table 5. Summary of Statistical Results

			p - value
One – way ANOVA			
Mix Proportions	Slump Test		0.000*
	Compressive Strength	14 days curing	0.452
		28 days curing	0.005*
	Water Absorption Rate		0.000*
Independent t – test			
Curing Days	Compressive Strength		0.145
Two – way ANOVA			
Mix Proportions and Curing Days	Compressive Strength		0.245

*Mean difference significant at the 0.05 level

Table 5 shows the statistical results using one-way ANOVA in which it suggests that different mix proportions were significantly different in terms of both slump height and water absorption (p=0.000). This finding indicates that the increasing proportion of coconut waste as partial coarse aggregate replacement affects both slump height and water absorption of concrete specimens. The result water absorption test agrees with [28] when banana fibers were used as supplementary aggregate for concrete. The same is true with [29], slump height significantly changed with respect to mix proportions of aggregates.

On the other hand, compressive strength in 14 and 18 days yielded different results. Unlike 28-day old concrete, the specimens cured for 14 days has no significant difference in terms of compressive strength (p=0.452). This suggests that the lack of significance in 14-day old concrete and significant difference in 28-day old concrete (p=0.005) are caused by the length of curing days.

Interestingly, based on multiple comparisons from Tukey HSD, no significant difference was found between the three mix proportions incorporated with coconut shells and coir fiber. This means that any of the proportions may be used without statistically significant difference at 0.05 level of significance. Moreover, in comparison to the control mix, the C-15 concrete specimen was the only concrete mix with no statistical difference in terms of compressive strength. Similarly, the result suggests that the 15% incorporation of coconut shell and coir fiber brings no significant effects to the concrete specimen in terms of compressive strength.

To attest the effects of curing days alone on the compressive strength of concrete specimen, an independent t-test was used. Statistically, the lengths of curing days are not significant to the compressive strength of concrete specimen. This means that 14-day old concrete has no statistically significant difference with 28-day old concrete in terms of compressive strength. With this result, the researchers developed the impression that curing days help in binding the concrete; however, this method alone does not improve the strength of the concrete specimen.Parallel with study of [30], compressive strength of concrete added with laterite did not significantly changed after 14-day curing. The same predicament was also observed in concretes added with corn cob ash [31]. The result showed insignificant change in compressive strength for 7, 14, and 28 days.

Results reveals that there is no statistically significant difference in terms of compressive strength as affected by the interaction of concrete mix proportions and curing days (p=0.245). Based on between-subject effects, the effect of concrete mix is significant (p=0.002), however, curing days obtained a p-value of 0.51, thus, implies no significant effect to the compressive strength. In the rational, the juxtaposition of curing days and mix proportions yielded an insignificant effect on the compressive strength. In view of this, it can be stated that the curing days should be extended to create a more significant effect on the concrete specimen.

Expanding the range of curing days from 7, 14 to 28 days is essential to be fulfilled as it helps in improving moisture content due to continuance of hydration reaction. In the reaction, moisture plays a vital role in the maintenance of a concrete specimen as this influence the desirable strength of the concrete. Preferably, the 28-day curing is the minimum length of time for curing of CS and CSF concrete specimen because it fulfills the need in durability, functionality, and serviceability properties [32].

Cost Analysis

Based on Table 6, the proportion of coconut waste is revealed to influence the total cost of production of the concrete specimen by varying differences. The reason behind this is the use of alternative aggregates as a replacement for gravel puts waste into good use while lessening the need to purchase bigger quantities of materials.

Table 6. Cost of Production Comparison

CHB Proportion	Cost per m^3	Cost difference*
C-0 (conventional)	1333.50	0 (0%)
C-15	1292.80	Php 40.7 (3.10%)
C-30	1248.80	Php 84.7 (6.56%)
C-45	1199.30	Php 134.2 (10.60%)

*values in parentheses are percent differences when compared to conventional CHB (C-0)

A similar case was studied in Iran, where the use of recycled aggregates reduced the total cost of production by as much as 32 % [33]. Although the cost difference in producing concrete with CSF aggregate is relatively lower, bear in mind that millions of cubic meters of concrete are produced in the Philippines if not worldwide. Therefore, this small difference can be transmuted to large amount of money and natural resources saved [34].

Coconut shells and coir fiber, being an agricultural waste, can be collected with no need for money. With this waste material replacing another in the concrete mix, practitioners will be able lessen the cost of production while reducing the volume of agricultural waste [35].

CONCLUSION AND RECOMMENDATION

The study proved that the addition of agricultural waste such as coconut shell (CS) and coir fiber (CSF) can be an alternative partial coarse aggregate to concrete hollow blocks (CHB). Results of the study revealed that average as workability by slump height decreased as the amount of CSF increased. Another, the compressive strength considerably reduced with increasing amount of CSF. And the amount of water absorbed was found to increase as the amount of coconut waste aggregate was increased.

In terms of curing days, statistical analysis showed no significant difference in the compressive strength between concrete specimens cured for 14 and 28 days. Furthermore, the interaction between mix proportions and curing days had no statistically significant effect in compressive strength of concrete specimen. Lastly, cost analysis also showed reduced production, by as much as 10.60%, when CSF is utilized, thus, cutting down the expenses while reducing the accumulation of agricultural waste.

Based on several specimens tested,CHB with CSF passed the American Society for Testing and Materials (ASTM) standards in terms of slump test, compressive strength, and water absorption test. The results of these effectiveness indicators suggest that CSF can be used as partial aggregate in making CSB.

Evidently, CSF has a vast potential to be used as coarse aggregates for non-load bearing concrete hollow blocks, as it was proven to be a viable replacement for conventional aggregates in terms of compressive strength, water absorption and workability.

This research is distinctive and innovative due to different ASTM methods and various statistical analysis applied. However, this research is still in its initial stage. Further study may consider the following: shape, size, and grading of the coarse aggregate, wherein, these aggregate dimensions can influence the workability and compressive strength of the material.

The study was limited to only 3 effectiveness indicators. Hence, additional effectiveness indicators such as: flexural strength (ASTM C78/C78M), sound proofing (ASTM E2179), life-span, and thermal conductivity. Also, concrete grades such as: M20, M25, and M30 can be studied.

The ASTM standards were mainly used in the study. Succeeding studies may also explore on using different mix designs and standards such as: British Method, ACI Method and Indian Standard as well as to create a 4" or 8" CHB for practical use. Forwarding to achieve the load bearing requirements, forthcoming studies may expand its materials and methods by prolonging the 28-day curing and using mass ration mixtures. Furthermore, utilization of other potential agricultural wastes as an aggregate can also be taken advantage.

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