UTILIZATION AND EVALUATION OF RICE HUSK ASH AND COCONUT SHELL ASH AS PARTIAL CEMENT REPLACEMENT FOR CONCRETE HOLLOW BLOCKS PRODUCTION

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UTILIZATION AND EVALUATION OF RICE HUSK ASH AND COCONUT SHELL ASH AS PARTIAL CEMENT REPLACEMENT FOR CONCRETE HOLLOW BLOCKS PRODUCTION

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Abstract: *Agricultural waste utilization can mitigate environmental threats from rice husks and coconut shells regarding waste management and disposal, such as turning these byproducts into ashes. Rice husk ash (RHA) and coconut shell ash (CSA) have been used to replace cement due to their pozzolanic properties. This investigation aimed to utilize and evaluate RHA and CSA as partial cement replacements for concrete hollow blocks (CHB). There were one control (0%) and 10%, 20%, and 30% replacements observed where each has the varied RHA and CSA proportions. CHB with 20% replacement (15% RHA, 5% CSA) has the highest mean compressive strength of 2.72 MPa, while 30% (15% RHA, 15% CSA) has the lowest mean water absorption of 110.909 kg/m3. Based on the findings, a conclusion is drawn that a combination of RHA and CSA can be utilized as a partial cement replacement for CHB.*

Keywords: Rice Husk Ash; Coconut Shell Ash; Compressive Strength; Water Absorption

1. INTRODUCTION

Rice is produced in large quantities in most of the world's agricultural nations, which results in the wasteful disposal of a substantial amount of rice husk into the natural environment. Rice husk or rice hull refers to the protective covering of rice grain. It is a lightweight and rugged coating that protects the seed during the growing season and is typically discarded when the grain is milled. But it is considered bulky and accounts for 20% (by volume) of a rice paddy harvest which traditionally challenges the farmers to find a way for its disposal [1]. Meanwhile, the Philippines is one of the leading producers of coconut goods for over 92 countries worldwide [2]. Yet the enormous amount of coconut production led to increased agricultural waste. Yet the enormous amount of coconut production led to increased agricultural waste. Waste from mature coconuts has been tightly controlled since there is a market for solid coconut fibers in various technical applications such as coir mattresses, automobile components, and coconut husk ash and coconut shell ash (CSA) for cement replacement. The environmental concerns regarding waste disposal of the aforementioned agricultural byproducts are mitigated by the discoveries on utilizing them, such as generating rice husk ash and coconut shell ash for various applications. Rice husks are burned in an oxygenic environment to release thermal energy and produce silica-rich ash [3]. Rice husk ash (RHA) can be utilized to make high-value-added goods as a sustainable source of silica that results in pozzoetclanic behavior [4], which leads to investigations on applying it as an additive to enhance the performance of concrete, and waste from mature coconuts has been tightly controlled because there is a market for solid coconut fibers in various technical applications such as coir mattresses, automobile components, coconut husk ash, and coconut shell ash (CSA) for cement replacement. Pozzolans are defined by the American Society of Testing Materials (ASTM) as siliceous or aluminous materials that have little or no cementitious capabilities. RHA and CSA have already been used to replace cement of concrete and concrete masonry units as they contain SiO_2, Al_2O_3, and Fe_2O_3, with a lower amount of CaO [5] [6]. Compared to Ordinary Portland Cement (OPC), RHA blended concrete improves the workability of concrete, increases compressive, tensile, and flexural strength, and aids in enhancing the early age mechanical and long-term strength properties of cement concrete [7]. The replacement of OPC with CSA is recommended for heavyweight and lightweight concrete production to increase its compressive strength [8]. Agricultural waste is difficult to dispose of because it can still pollute the environment. When utilized in concrete, however, it is advantageous as it will save cost and minimize the use of cement in concrete structures, lower carbon dioxide emissions linked with cement manufacture, and consider the building's stability must [9][10]. Partially replacing cement with a combination of materials for cement replacement is cost-effective. However, it also has mechanical, durability, and microstructural advantages [11]. From the information presented above, this research aimed to investigate the viability of using a mixture of ashes derived from rice husks and coconut shells as a partial cement replacement in manufacturing concrete hollow blocks.

2. METHODOLOGY

2.1 Preparation of Materials

The rice husks and coconut shells were subjected to sun-drying to remove moisture. Then, it was subjected to uncontrolled combustion through an open-air burning and allowed to cool. Then, the materials were sent to the hollow block-making station.

2.2 Hollow Blocks Production

2.2.1 Mix Proportioning

The CHB had three cement replacements: 10%, 20%, and 30% of the total weight of cement. Each cement replacement had five different proportions of RHA and CSA. RHA only (T1, T6, T11), CSA only (T2, T7, T12), same level of RHA and CSA (T3, T8, T13), lower RHA with higher CSA (T4, T9, T14), and higher RHA than CSA (T5, T10, T15). The combination resulted in 15 mixes plus one control (T0) mix with no cement replacement (0%)—16 mixes. Since two properties of CHB were tested (compressive strength and water absorption), and three specimens were used in each case (16 x 2 x 3), there were 96 specimens in total. Consequently, the recommended amount of ingredients by the designated mason of the hollow block station that 5kg of cement mixed with one sack of sand and an estimated amount of water can produce approximately seven specimens was used as the basis. Therefore, every treatment was prepared by decreasing 5kg with the weight percentage according to a specific replacement. The replaced amount of cement was substituted with a particular proportion of RHA and CSA.

2.2.2 Mixing

The sand, cement, and the RHA and CSA were mixed for partial cement replacement as shown in figure 1. Then water was slowly added to the mixture.

Figure 1. Mixing

2.2.3 Transforming

The mixture was gradually placed into a hollow block molder of 100×200×400 mm dimension for nominal size CHB until the mold was adequately filled and compacted.

Figure 2. Molded CHBs

2.2.4 Curing

After removal from the hollow block molder, the CHBs were subjected to 28 days of curing [4]. The curing was achieved by continually sprinkling them with water.

2.3 Quality Testing

The following procedures were carried out according to the ASTM C140 - Standard Test Methods for Sampling and Testing Concrete Masonry Units and Related Units.

2.3.1 Compressive Strength

The specimens after cured until the surface has dried. Then, using the Universal Testing Machine, compressive strength will be determined by increasing loads to the sample until it fails. Compressive strength was calculated as follows:

$$Compressive\ strength, C = \frac{W}{A} \qquad \text{eq (1)}$$

where:

C = compressive strength of the specimen, (MPa)
W = maximum load, (kN), indicated by the testing machine
A = average of the gross areas of the upper and lower bearing surfaces of the specimen (mm^2).

2.3.2 Water Absorption

2.3.2.1 Saturation Process

The test specimens were immersed in water at room temperature for 24 h. The samples were then weighed while suspended by a metal wire and submerged in water to record Wi (immersed weight). Then, the CHBs were allowed to drain—removing visible surface water and weighed and recorded as Ws (saturated weight).

2.3.2.2 Drying Process

After saturation, all specimens were dried in a ventilated oven at 212 to 239°F (100 to 115°C) for not less than 24 hours; Wd (oven-dry weight) was then recorded.

2.3.2.3 Calculation

The water absorption calculates as given below:

$$WA = \frac{Ws-Wd}{Ws-Wi} x100 \qquad (2)$$

Where:

WA = water absorption, (kg/m^3)
Ws = saturated weight of specimen, (kg)
Wd = oven-dry weight of specimen, (kg)
Wi = immersed weight of specimen, (kg)

2.4 Data Analysis

Statistical analysis was performed to evaluate further data from measuring the compressive strength and water absorption test. The significance of adding RHA and CSA to the compressive strength and water absorption of the specimens was analyzed with a one-way analysis of variance (One-way ANOVA) procedure using Statistical Tool for Agricultural Research (STAR) software at a 5% level of significance.

3. RESULTS AND DISCUSSIONS

Statistical analysis was performed to evaluate further data from measuring the compressive strength and water absorption test. The significance of adding RHA and CSA to the compressive strength and water absorption of the specimens was analyzed with a one-way analysis of variance (One-way ANOVA) procedure using Statistical Tool for Agricultural Research (STAR) software at a 5% level of significance.

3.1 Compressive Strength

Compressive strength results were obtained from an average of three concrete cube specimens. Figure 3 shows the average compressive strength of each RHA and CSA composition of every cement replacement, including that of the control set-up, wherein the T10,

CHB with 20% partial cement replacement at proportion with higher amount of RHA than CSA (15% RHA, 5% CSA) has the highest compressive strength, followed by T9 (5% RHA, 15%CSA), both higher than with no replacement (T0). This phenomenon is probably caused by the reaction of RHA and CSA being combined in replacing cement of CHB. It can also be observed that as the percent cement replacement gets higher than 10%, there is an increase in compressive strength—contradicting the findings that 10% is the optimum percentage replacement of OPC with CSA [12] and RHA [13] in terms of compressive strength. Interestingly, T1 (10% RHA) and T2 (10%CSA) that are noticeably composed of only one type of ash have similar average compressive strength. At 10% replacement, RHA and CSA have the same impact on the compressive strength of CHB.
In the case of 30% replacement, the amount of silica accessible is likely too large, and the amount of calcium-hydroxide available is most likely inadequate to react with all the available silica, leaving some silica unreacted chemically. The reduced cement caused the loss of strength. As a result, the amount of calcium-hydroxide released was insufficient to react with the available silica. The silica behaved as an inert substance without contributing to the development of strength [14] [7]. This causes the minimum compressive strengths of the treatments to be under 30% replacement.

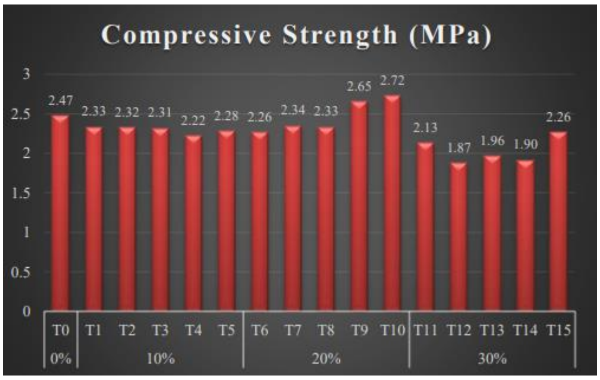

Figure 3. Compressive Strength of the concrete hollow blocks

In Table 1, wherein the treatments are arranged according to compositions of RHA and CSA, it can be noted that the proportions have their maximum compressive strength at 20% replacement except for RHA only, where the highest compressive strength is at 10%, it conforms with the report of Habeeb & Mahmud [15] that after replacing cement of Ferro-cement furnace and M. Mohamed Barveen & K. Gunasekaran [24] after replacing ordinary Portland cement with RHA, the maximum compressive strength was obtained at 10% replacement. Different from the findings that an increase in the concrete's compressive strength was observed as the amount of RHA gets higher [16] and with the conclusion of Oyetola & Abdullahi [17] that the optimum replacement of RHA for a concrete block is 20%. Meanwhile, the proportion containing only CSA has obtained its highest strength of compression at 20% replacement (T2), mismatches the claim that replacing Ordinary Portland Cement (OPC) with 10% CSA has the effective pozzolanic behavior increasing the compressive strength of concrete [12].

3.2 Water Absorption

In figure 4, the data points are the means of water absorption for each percentage of cement replacement and varied proportions of RHA and CSA. Water absorption refers to the movement of liquids within solid pores caused by surface tension in capillaries. Concrete pore structure characterization is well established to be one of the essential factors affecting the material's durability. The higher the water absorption, the less durable the concrete unit is [18].

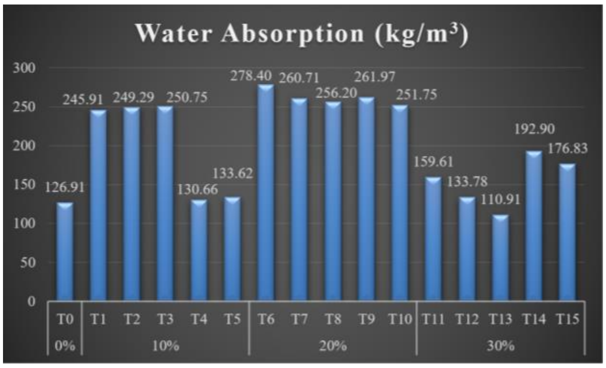

Figure 4. Water Absorption of the concrete hollow blocks

Table 1. Compressive Strength according to RHA and CSA proportion

Treatment	CR %	RHA %	CSA %	Compressive Strength (MPa)
T0	0%			2.47
T1	10%	10%		2.32
T6	20%	20%		2.26
T11	30%	30%		2.13
T2	10%		10%	2.32
T7	20%		20%	2.34
T12	30%		30%	1.87
T3	10%	5%	5%	2.31
T8	20%	10%	10%	2.33
T13	30%	15%	15%	1.96
T4	10%	2.5%	7.5%	2.22
T9	20%	5%	15%	2.65
T14	30%	7.5%	22.5%	1.90
T5	10%	7.5%	2.5%	2.27
T10	20%	15%	5%	2.72
T15	30%	22.5%	7.5%	2.26

*CR- Cement Replacement, RHA- Rice husk ash, CSA- Coconut shell ash

The water absorption of CHBs in all RHA and CSA proportions, with RHA only (T1, T6), CSA only (T2, T7), the same level of RHA and CSA (T3, T8) with lower RHA and higher CSA (T4, T9) and with higher RHA than CSA (T5, T10) escalates as the percent of cement replacement increases from 10% to 20%, conforming what Balapogal & Viswanathan [19] concluded. It can be noticed in the graph that the treatments with the lowest water absorption capacity lie in the 10% replacement (T4, T5) and 30% replacement (T11, T12, T13). Adeala [20] also reported that increased coconut shell ash replacement has reduced water absorption. This is probably caused by the property of coconut shells that absorb less moisture due to their low cellulose content [21]. T13 obtained the minimum mean water absorption (15% RHA, 15% CSA), the only treatment with lower water absorption than the control samples (T0).

Table 2. Water Absorption according to RHA and CSA proportion

Treatment	CR %	RHA %	CSA %	Water Absorption (kg/m^3)
T0	0%			126.91
T1	10%	10%		245.91
T6	20%	20%		278.4
T11	30%	30%		159.61
T2	10%		10%	249.29
T7	20%		20%	133.62
T12	30%		30%	133.78
T3	10%	5%	5%	250.75
T8	20%	10%	10%	256.2
T13	30%	15%	15%	110.91
T4	10%	2.50%	7.50%	130.66
T9	20%	5%	15%	261.97
T14	30%	7.50%	22.50%	192.9
T5	10%	7.50%	2.50%	133.62
T10	20%	15%	5%	251.75
T15	30%	22.50%	7.50%	176.83

*CR- Cement Replacement, RHA- Rice husk ash, CSA- Coconut shell ash

The observation is supported by Table 2, which entails the water absorption capacity of specimens arranged according to the composition of RHA and CSA. The highest water absorption is at 20% replacement in proportion with only RHA. This is because of the absorptive nature of RHA, the higher RHA replacement used in the concrete will absorb more water during the curing process as when the amount of RHA replacement increases, so does the percentage of water absorption [22], but at its 30% replacement, it reaches its lowest value which then relates to the idea that increased RHA loading reduces the water absorption capacity of cement concrete because the fine RHA particles occupy the delicate pores and inter-particle gaps which makes the water absorption capacity reduced [23]. While with only CSA, the lower water absorption decreases while the loading increases, and 20% and 30% replacements have too close values, in contrast with the report that at 10% replacement of OPC with CSA, the minimum water absorption was obtained [12]. The remaining proportions behave likely with only RHA as water absorption increases from 10% to 20% loading, then a decrease follows at 30%. It implies that the escalation of replacement has no definite relation with the proportion of RHA and CSA.

3.3 Statistical Analysis

Statistical analysis was used to examine the data acquired from the water absorption and compressive strength tests. The difference between the computed dependent variables with the treated specimens and the control was determined using the F Test with the One-Way ANOVA approach. It analyzes the difference between the calculated dependent variables with the treated samples and the control (without cement replacement). This would determine whether the RHA and CSA significantly impact the examined variables.

Table 3 shows a significant difference in the compressive strength across different treatments, with a pvalue=0.0000 which is less than the p-value of 0.05. The tested proportions have significantly different compressive strengths when compared with one another. This implies that the proportions of RHA and CSA have different compressive strength levels.

Table 3. Analysis of Variance for the Compressive Strength of CHB

		Degree of freedom	Sum of Squares	Mean square	*F* value	*P*-value
Compressive Strength	Treatment	15	2.4504	0.1634	19.07	0.0000*
	Error	32	0.2742	0.0086		
	Total	47	0.2742			

*P-value ≤ 0.05 means there is a significant difference

Table 4. Tukey HSD Post-hoc Test for the Compressive Strength of CHB

Treatment	CR %	RHA %	CSA %	Compressive Strength (MPa) ± SD
T0	0%	0%	0%	2.47 ± 0.05[ab]
T1		10%	0%	2.32 ± 0.09[bc]
T2		0%	10%	2.32 ± 0.13[bc]
T3		5%	5%	2.31 ± 0.12[bc]
T4	10%	2.5%	7.5%	2.22 ± 0.12[bcd]
T5		7.5%	2.5%	2.27 ± 0.07[bc]
T6		20%	0%	2.26 ± 0.09[bc]
T7		0%	20%	2.34 ± 0.10[bc]
T8	20%	10%	10%	2.33 ± 0.06[bc]
T9		5%	15%	2.65 ± 0.07[a]
T10		15%	5%	2.72 ± 0.09[a]
T11		30%	0%	2.13 ± 0.03[cde]
T12		0%	30%	1.87 ± 0.12[e]
T13	30%	15%	15%	1.96 ± 0.12[de]
T14		7.5%	22.5%	1.90 ± 0.08[e]
T15		22.5%	7.5%	2.26± 0.09[bc]

*CR- Cement Replacement, RHA- Rice husk ash, CSA- Coconut shell ash; Means with the same letter are not significantly different (P<0.05) based on the Tukey HSD test

Tukey HSD post-hoc test was utilized to identify which treatments have significantly different compressive

strength and water absorption. Treatments with the same letters are not entirely different treatments—there is not sufficient evidence to say that these treatments are different from each other. However, treatments with different letters show a significant difference—conclusive evidence that these treatments are different. From table 4, T1, T2, T3, T5, T6, T7, T8, and T15 have the same level of compressive strength. Meanwhile, T4 has a very relative compressive strength compared with T13 and T11, but it has a significantly higher compressive Strength than T12 and T14. Both T9 and T10 have the highest level of compressive strength, almost identical to T0. However, these treatments have a significantly higher value than any other treatments.
The water absorption of concrete hollow blocks also shows a significant difference between the treatments. Table 5 shows the p-value of 0.000, which is less than 0.05. This implies that the treatments considerably affect the water absorption of the CHBs. Since the variance analysis shows a significant difference, the Tukey HSD posthoc test was then used to determine which treatments differed significantly. Still, treatments with the same letters are not significantly different.

Table 5. Analysis of Variance for the Water Absorption of CHB

		Degree of freedom	Sum of Squares	Mean square	*F* value	*P*-value
Water Absorption	Treatment	15	167079.2717	11138.6181	23.00	0.0000*
	Error	32	15494.8425	484.2138		
	Total	47	182574.1142			

*P-value ≤ 0.05 means there is a significant difference

For water absorption, there are only a few significantly different pairs. It can be noticed in Table 6 that several treatments have the same letters, hence, the same level of water absorption. Treatments 6, 7, and 9 have the highest water absorption level, while T13 significantly has the lowest water absorption capacity.

3.4 Selection of the Best Mix

After conducting One-way ANOVA and Tukey's HSD Post-hoc Test on Compressive Strength and Water Absorption, the best treatment in every variable was considered. There was a significant difference between the compressive strength of the CHB, but T9 (5% RHA, 15% CSA) and T10 (15% RHA, 5% CSA) has significantly obtained the maximum level of compressive strength. From the standpoint of Water Absorption, T13 (15% RHA, 15% CSA) has the lowest level.
Considering that the better treatment must have higher compressive strength and lower water absorption, it can be noted that the increase in compressive strength cannot guarantee the reduction of water absorption and vice versa. Therefore, separate consideration of the best mix of RHA and CSA was done according to compressive strength and water absorption. This study suggests that the recommended combinations in standpoint of compressive strength are T9 (5% RHA + 15% CSA) and T10 (15% RHA + 5% CSA). While for the standpoint of water absorption, the preferred mix is T13 (15% RHA + 15% CSA).

Table 6. Tukey HSD Post-hoc Test for the Water Absorption of CHB

Treatment	CR %	RHA %	CSA %	Compressive Strength (MPa) ± SD
T0	0%	0%	0%	126.91 ± 35.09^{cd}
T1		10%	0%	245.91 ± 17.56^{ab}
T2		0%	10%	249.29 ± 0.90^{ab}
T3	10%	5%	5%	250.75 ± 5.75^{ab}
T4		2.5%	7.5%	130.66 ± 2.71^{cd}
T5		7.5%	2.5%	133.62 ± 14.49^{cd}
T6		20%	0%	278.40 ± 4.42^{a}
T7		0%	20%	260.71 ± 8.02^{a}
T8	20%	10%	10%	256.20 ± 22.60^{ab}
T9		5%	15%	261.97 ± 66.58^{a}
T10		15%	5%	251.75 ± 5.89^{ab}
T11		30%	0%	159.61 ± 8.34^{cd}
T12		0%	30%	133.78 ± 4.55^{cd}
T13	30%	15%	15%	110.91 ± 12.50^{d}
T14		7.5%	22.5%	192.90 ± 20.64^{bc}
T15		22.5%	7.5%	176.83 ± 14.89^{cd}

*CR- Cement Replacement, RHA- Rice husk ash, CSA- Coconut shell ash; Means with the same letter are not significantly different (P<0.05) based on the Tukey HSD test

4. CONCLUSIONS

After utilizing and evaluating rice husk ash (RHA) and coconut shell ash (CSA) as partial cement replacement for concrete hollow blocks, the following conclusions based on the gathered data obtained from the results of the tests are summarized as follows:

1. The concrete hollow blocks obtain the highest mean compressive strength with 20% cement replacement containing a higher amount of RHA than CSA. In comparison, the lowest mean compressive strength is attained by 30% cement replacement with CSA only.
2. Concrete hollow blocks obtain the lowest mean water absorption with 30% cement replacement containing the same level of RHA as CSA. The highest mean water absorption is attained by the cement replacement with lower RHA than CSA.
3. There is a significant difference between the compressive strength and water absorption of concrete hollow blocks with and without RHA and CSA as partial cement replacement.
4. The best mixes in standpoint of compressive strength are CHB with (5% RHA, 15% CSA) and (15% RHA, 5% CSA), and for the water absorption is (15% RHA, 15% CSA).
5. Concrete hollow blocks with RHA and CSA as partial cement replacements obtain higher compressive strength and lower water absorption than conventional CHBs. Therefore, RHA and CSA can be utilized as cement replacements for CHB.

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