Utilizing Rice Husk Ash and Coconut Shell as Partial Replacement Materials in Concrete

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ABSTRACT

The global demand for concrete, a predominant construction material, has risen significantly. Key components in concrete are cement and aggregate, which are crucial, but their continual extraction poses a threat to the environment, leading to a potential ecological imbalance. Consequently, current trends in concrete technology focus on exploring sustainable alternatives to reduce dependence on natural resources and mitigate environmental degradation. This study aimed to produce concrete using rice husk ash and coconut shell as partial replacement materials for cement and coarse aggregate, respectively. The mix ratio is 1:2:4 (cement: fine aggregate: coarse aggregate) for grade M20 with the water-cement ratio 0.65. Rice husk ash replaced 10% and 20% of cement, while coconut shell replaced 5% and 10% of coarse aggregate by weight. Samples were tested for workability, water absorption, and compressive strength. According to the slump test, every sample exhibits collapse and a true slump, while in water absorption showed less than 8% according to the standard value. The control sample showed good compressive strength (>20 N/mm^2), while among the modified samples, the concrete mixture with 10% rice husk ash and 5% coconut shell achieved the highest compressive strength at 15 N/mm^2 after 28 days.

KEYWORDS

concrete; coconut shell; rice husk ash; workability; compressive strength

1. INTRODUCTION

As one of the primary sectors of the national building industry, construction is crucial to a nation. According to (The Star, 2023), Malaysia's construction industry is predicted to expand greatly as a result of increased government investment and private-public sector efforts. However, the materials utilised in building, such as cement and aggregate, are going to be depleted. Environmental issues including habitat destruction, erosion, and carbon dioxide emissions can result from the depletion of natural resources and raw materials.

Two major environmental effects of the concrete industry are global warming and ozone layer degradation (Omar & Muthusamy, 2022; Patil & Paliwal, 2020). Malaysia ratified the Kyoto Protocol in 2002 and has taken initiatives to lower its carbon emissions as reported by (Musa, 2024). Reducing raw resources by partially replacing some of them is one of his strategies. This helps to reduce the need for excessive use of these non-renewable resources, ensuring a sustainable and eco-friendly alternative to conventional building materials. (J et al., 2023) note that minor cracks in concrete result from shrinkage, prompting the construction industry to explore new compositions with natural additives.

Coconut shell and rice husk ash (RHA) were chosen based on research findings that highlight the material's characteristics and benefits. Coconut shells have high water and acid resistance, as well as reduced shrinkage, which improves workability and strength in concrete (Kanojia & Jain, 2017). (Amin & Abdelsalam, 2019; Khan et al., 2021; Phatak & Kishor, 2024) Research on rice husk ash (RHA), which is an effective super pozzolan containing 85-90% silica, shows a significant improvement in concrete's durability by reducing air content and water permeability through the use of a high ratio of RHA and fly ash. The related earlier studies have discovered that the testing findings are impacted by the proportion, particle properties, and replacement purpose of material used in concrete (Arora et al., 2023; Herring et al., 2021; Phatak & Kishor, 2024).

This study aims to assess the workability, water absorption, and compressive strength of concrete with rice husk ash and coconut shell as partially replacements for cement and coarse aggregate, respectively.

2. METHODOLOGY

Figure 1 visualizes the methodology of the study conducted. The concrete consists of Ordinary Portland Cement (OPC), fine aggregate less than 10 mm and coarse aggregates generally between 5 mm and 20 mm. The partial replacement material size is particles ranging in size from 5 to 10 μm of RHA and a sharp fracture of coconut shell with the size 10 mm to 20 mm. The ratio of concrete mix is 1:2:4 with a grade of M20 with the water-cement ratio of 0.65. In the study, the cement is partially replaced with 10% and 20% of RHA while the coarse aggregate is replaced with 5% and 10% of coconut shell by weight. A control sample with 0% replacement is used as a reference, and three samples are developed for each replacement ratio throughout testing. A total of 45 cubes with sizes of 150 mm x 150 mm x 150 mm were prepared. The sample preparation is shown in Table 1.

The workability (MS 26-1-2:2009), water absorption (MS EN 1097-6:2011) and compressive strength (EN 12390-3:2012) tests were conducted at Chuan Seng Industries Sdn. Bhd. as shown in Figure 2 and Figure 3. The prepared samples have been evaluated on 7, 14, and 21 days for water absorption and compressive strength tests. The slump test is crucial for measuring the workability of fresh mixed concrete, ensuring uniformity and strength. It helps identify variations in the mix's homogeneity, which is essential for correct placement and compacting, and indirectly reveals the water content. The concrete's durability is determined by its porosity, which is influenced by its ability to absorb water. A water absorption test is conducted to assess the concrete's permeability, ensuring a low rate of absorption, indicating its high quality and resistance to degrading elements. The compressive strength standard is crucial for quality control in concrete to ensure the mix meets the intended weights under compressive loads, ensuring durability and long-term performance.

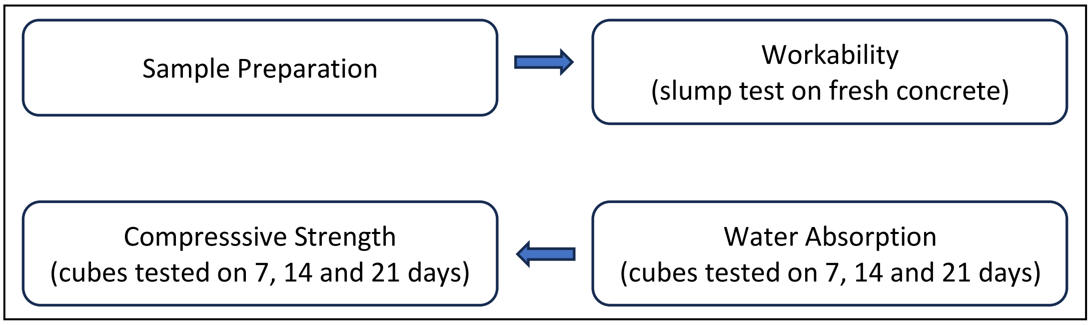

Figure 1. Methodology of the study

Table 1. Sample preparation

Sample	Ratio 1 : Cement (kg)	2 : Fine Aggregate (kg)	3 Coarse Aggregate (kg)	Rice Husk Ash (kg)	Coconut Shell (kg)	Total Sample
Control Sample	12.08	24.16	48.31	0	0	9
A	10.87	24.16	45.90	1.21 (10%)	2.42 (5%)	9
B	9.66	24.16	45.90	2.42 (20%)	2.42 (5%)	9
C	10.87	24.16	43.48	1.21 (10%)	4.84 (10%)	9
D	9.66	24.16	43.48	2.42 (20%)	4.84 (10%)	9

Figure 2. Concrete mixture

(a) **(b)** **(c)**

Figure 3. a) Slump test b) Water absorption test c) Compressive strength

3. RESULTS AND DISCUSSION

3.1 Slumpt Test (MS 26-1-2:2009)

Referring to Table 2, the slump test results indicate that the control sample obtained the slump value of 120 mm. Sample A shows a slump of 130 mm, sample B records 65mm, sample C is 30mm, and sample D is 27mm. The highest recorded value of slump height is for sample A with 10% RHA and 5% coconut shell, which is 130mm, and the lowest is 27 mm of sample D with 20% RHA and 10% coconut shell of cement and coarse aggregate repalcements, respectively as illustrated in Figure 4. Besides, the control sample and sample A demonstrated high workability as indications of a collapse slump. This is ideal for constructing beams, reinforced walls, and building columns that are not normally suitable for vibration. This type of concrete is also best used for leancon purposes and casting slabs that have a low load. Sample B had medium workability and can be utilized as a slab, huge construction mass and deck of bridge. On the other hand, samples C and D exhibit a true slump with low workability. Since this research is using G20 concrete, making them suitable for used in pre-cast panels like scupper drain concrete covers, road pavement, and slab construction due to the limited water content that accelerates concrete hardening.

Based on research (Rajendran & Rahman, 2022), the concrete has better workability because of the smaller size and smooth surface on one side of coconut shells. However, increasing amounts of coconut shells in concrete can reduce it's workability (Arora et al., 2023; Herring et al., 2021). More water is required to lubricate all the ingredients, and more glue is required to bind the paste as the surface area grows. Since each aggregate shape has a varied surface area and frictional resistance, combining them becomes challenging (Azahar & Rahman, 2021). Compared to cement, RHA has a substantially larger surface area, which increased the need for water. The slump value will be decreased as RHA increases, hence lower workability (Anita et al., 2018; Khan et al., 2021).

Table 2. Slump test

Sample	**Control Sample**	**A**	**B**	**C**	**D**
Slump					
Slump Value	120 mm	130 mm	65 mm	30 mm	27 mm
Type of Slump	Collapse	Collapse	True Slump	True Slump	True Slump
Workability	High	High	Medium	Low	Low
Application	Normal reinforced concrete construction work		Slab, beam, huge mass construction, deck of bridge,	Pavement, road construction, huge mass construction	

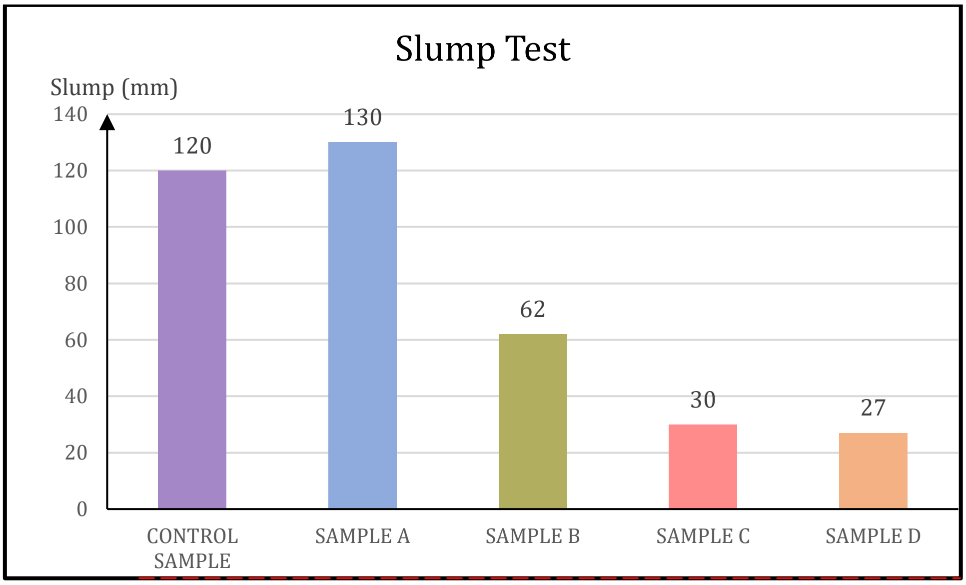

Figure 4. Slump test of samples

3.2 Water Absorption Test (MS EN 1097-6:2011)

Table 3 and Figure 5 indicate that the control sample has achieved the highest result in the water absorption test which is 2.66%, followed by sample A at 1.96%, sample B at 0.56%, sample C at 0.50%, and sample D is 0.20% after 28 days of curing. According to the standard requirement, all samples show lower water absorption, which is less than 8% of the Malaysian Public Works Department's (JKR) requirement (MS30). The control sample and sample A have high absorption due to low partial replacement material compared to samples B, C and D based on RHA and coconut shell ratios.

RHA and coconut shell in concrete can balance water absorption by generating a denser matrix and reducing porosity. Coconut shell aggregates have a high water absorption capacity due to their porous structure, which increases total water absorption; otherwise, it will decrease the compressive strength (Azahar & Rahman, 2021; Herring et al., 2021). In between, the concrete matrix's pores are filled with RHA, a high pozzolanic reactivity that increases durability and reduces water absorption and permeability. According to (Gabriel et al., 2020; Mounika et al., 2022) research, the application of pozzolanic materials such as rice husk ash in concrete decreases its water absorption capacity. Furthermore, the research found that higher pozzolanic content can further reduce water absorption values. This is demonstrated in sample D, which contains 20% rice husk ash and 10% coconut shell. The impact of RHA on water absorption is evident, showing better absorption than the control sample.

Table 3. Water absorption test

Sample	**Water Absorption (%) $\frac{W2-W1}{W2}$ x 100**		
	7 Days	**14 Days**	**28 Days**
Control Sample	3.55	2.70	2.66
A	1.10	1.17	1.96
B	0.33	0.47	0.56
C	4.60	1.80	0.50
D	0.90	0.10	0.20

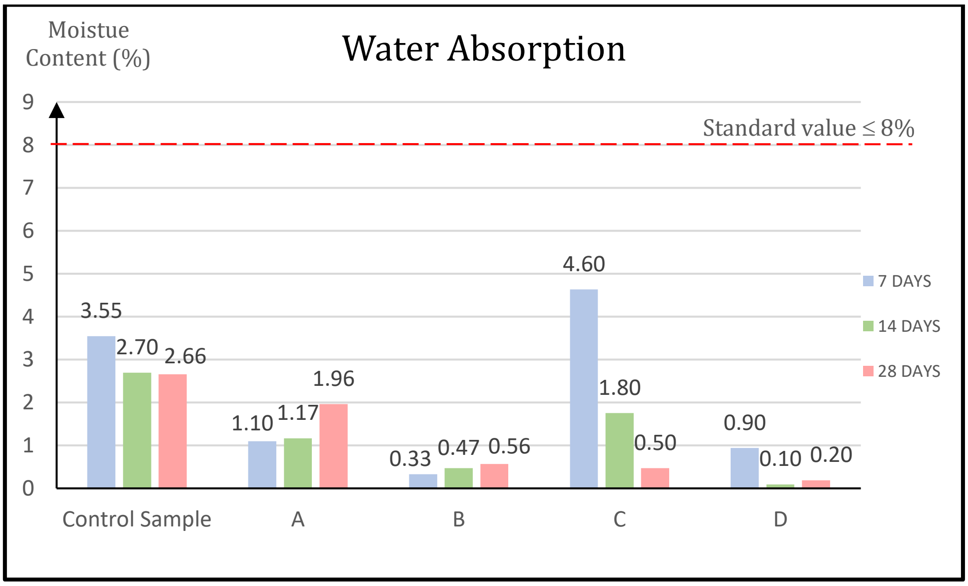

Figure 5. Water absorption test of samples

3.3 Compressive Strength (EN 12390-3:2012)

Table 4 presents data from the compressive strength test, indicating that the control sample achieved the highest compressive strength among all samples, which is more than the standard value. Referring to Figure 6 to Figure 8, none of the samples, except the control sample, met the Jabatan Kerja Raya Specification compressive strength requirement of 14 N/mm^2, 18 N/mm^2 and 20 N/mm^2 on the 7, 14, and 28 days respectively. The results showed that the concrete's compressive strength gradually decreased as the amount of RHA and coconut shell added increased. Referring to research (Liu et al., 2022; Sathe et al., 2023), the same results were also obtained. While RHA reduces water absorption, it does not enhance compressive strength (Al-Alwan et al., 2024). Utilizing coconut shell as a partial replacement for coarse aggregate will lower the concrete density but doesn't increase compressive strength with increased replacement percentages due to the porous and irregular nature of coconut shells.

By the 28 days as shown in Figure 8, sample A achieved a compressive strength of 15 N/mm^2, highest among the modified samples, while the control sample remained above the standard at 20 N/mm^2. Sample A is suitable for lean concrete and non-structural work, even below grade M20. However, all the samples show a similar pattern of increasing in compressive strength from 7 to 28 days, as indicated in Figure 9. Some researchers (Phatak & Kishor, 2024; Rajendran & Rahman, 2022; Uzni & Hanapi, 2021) have proposed that only a smaller percentage of RHA and coconut shell is suitable to be used as replacement materials in concrete due to the opposite impact of increased replacement materials on compressive strength.

Table 4. Compressive strength

Sample	**Compressive Strength (N/mm^2)**		
	7 Days	**14 Days**	**28 Days**
Control Sample	17	20	24
A	10	13	15
B	6	8	10
C	8	11	12
D	8	9	13

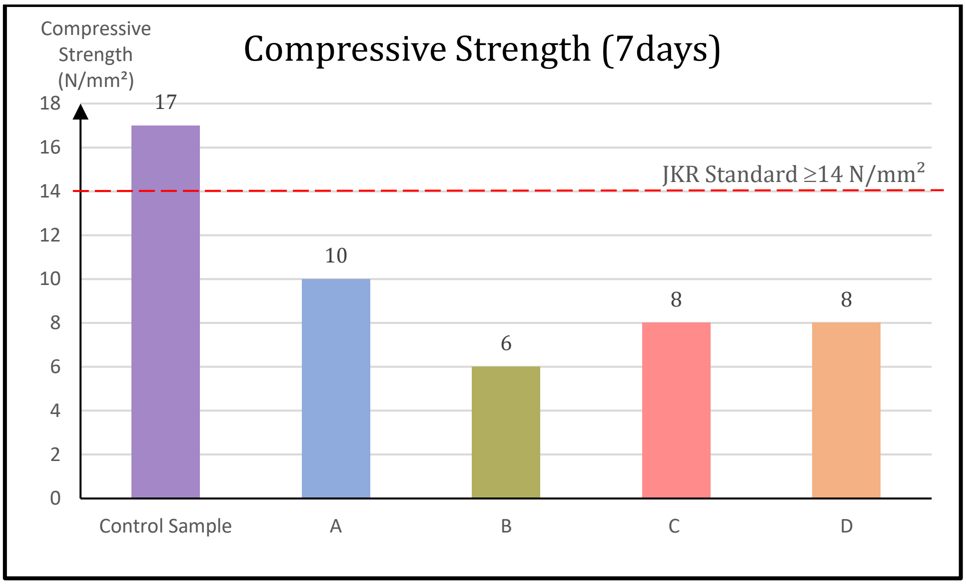

Figure 6. Compressive strength of samples at 7 days

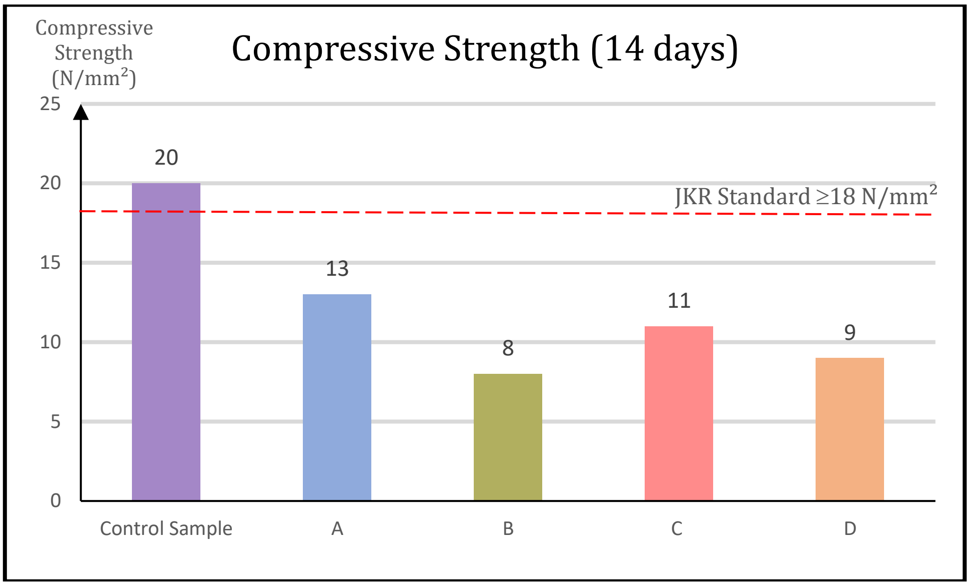

Figure 7. Compressive strength of samples at 14 days

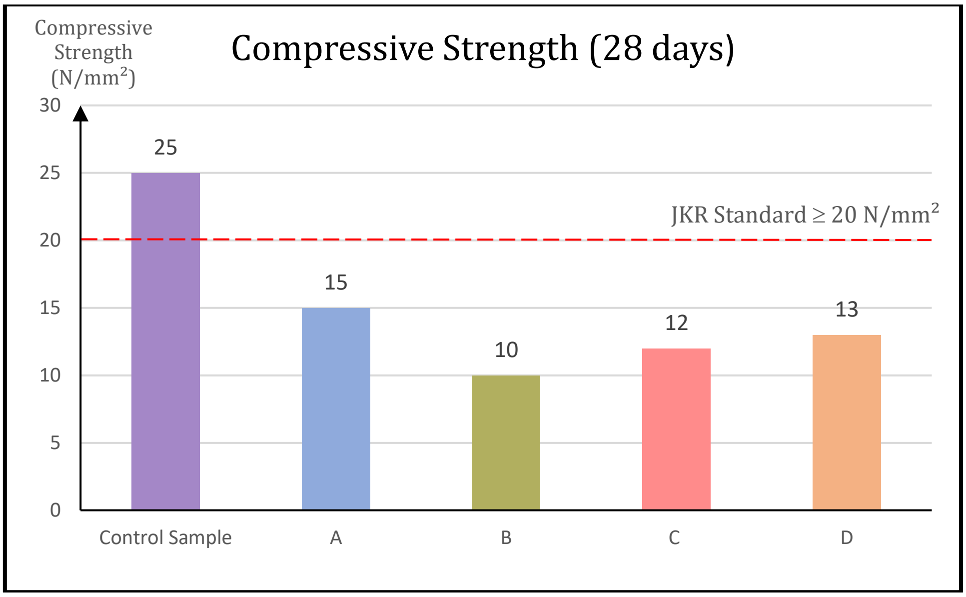

Figure 8. Compressive strength of samples at 28 days

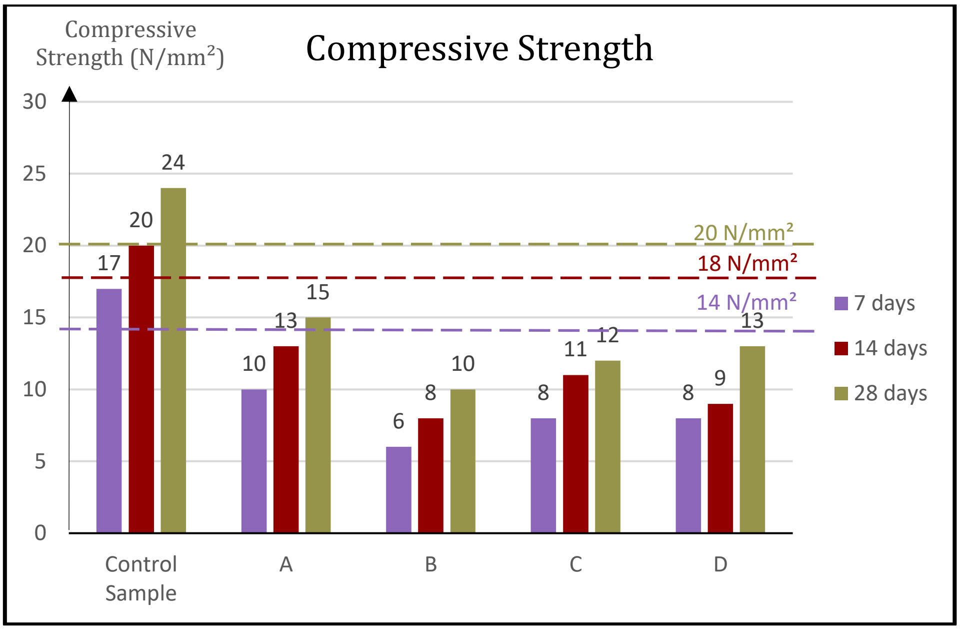

Figure 9. Comparison of samples' compressive strength

4. CONCLUSION

One crucial aspect of a concrete mixture is its workability, which is measured by concrete slump. The study findings indicate that the replacement of 10% of rice husk ash in cement and 5% of coconut shell in coarse aggregate of sample A shows good workability among all the other samples.

In this research, sample D has the lowest water absorption compared to the other samples. As water absorption increases, a higher coconut shell content is also associated with less workability in concrete (Herring et al., 2021). Inadequate compaction due to poor workability can result in gaps in the concrete, increasing shrinkage and lowering compressive strength. In order to establish adequate bonding, more cement paste may be needed. Conversely, the RHA can reduce drying shrinkage in concrete when used in place of some of the cement because the pore size refinement and fineness improve interlocking of particles in the transition zone (Mounika et al., 2022). Further research is necessary to better understand the behavior of the material with high water content because the compressive strength diminishes as water enters the pores.

For the compressive strength test obtained, the control sample and sample A have the highest concrete strength. However, only the control sample has achieved the concrete strength standard of 20N/mm^2 at 28 days while sample A has achieved 15N/mm^2. The compressive strength of other samples is decreasing with an increase in RHA and coconut shell percentage replacement in concrete. This suggests that a smaller percentage of replacement materials results in higher compressive strength. Futher, (Azahar & Rahman, 2021; Ranjith, 2023; Verma & Shrivastava, 2019) reported the coconut shell can be classified as lightweight aggregate based on the lighter density compared to conventional concrete, which can be used in non-structural components without effecting the strength of some structures. In-depth studies on the performance of concrete based on variables including the water-to-cement ratio, particle size and shape, the characteristics and proportions of replacement cement components, and the curing process ought to be addressed in the future.

As a conclusion, utilizing agricultural waste materials such as RHA and coconut shell as partially replacement materials in concrete not only expands our understanding of agricultural waste potential use to improve certain properties of concrete, such as workability, durability, and strength, but also contributes to enhancing construction sustainability and reducing environmental impact in terms of raw resource control, financial cost, and waste disposal issues.

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