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A Study of Rice Husk Ash on the Strength of Concrete

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Abstract

Ordinary Portland Cement(OPC) is a crucial component in concrete mixtures however its manufacture results in high carbon emissions. This paper present the rice husk ash(RHA) potential as a partial replacement for 8%, 9%, 10%, 11% and 12% of cement. The use of agricultural waste products in concrete mixture had received great attention due to their environmental benefits and their potential to improve concrete properties. RHA contains high silica content which enhances its reactivity and makes it suitable for use in cement bases materials. It aim to investigate the degree of workability and the compressive strength of concrete. The degree of workability was measured through the use of slump test and compressive strength were determined by testing the concrete cubes after 7 and 28 days of curing. A total of 36 concrete cubes of 100mm×100mm×100mm were casted and tested to determine the compressive strength. The results showed the slump values ranged from 54 mm (0% RHA) to 34 mm (12% RHA) indicate that workability decreased consistently with increased RHA percentage. The optimum RHA was 9% replacement with 22.6 Mpa at 28 days. The targeted performance value was 28 Mpa after 28 days according to control samples. The study does not achieve the targeted requirement strength of 28 MPa after 28 days and the compressive strength of all RHA mixes was also lower than the control mix. The study reached its objective on the impact of RHA on workability and the compressive strength of concrete and indicate that the performance can be improved with better RHA processing and optimum mix design as the result of the strength fell short from the design aim. This potential can be optimized by using RHA and therefore offer further environmental advantages including resource saving and agricultural waste management when used in concrete as a partial substitute for cement.

1. Introduction

There has been a long standing interest in the use of agricultural waste products in concrete mixture due to their environmental benefits and their potential to improve concrete properties. Rice husk ash is the residue obtained from the combustion of rice husk which is the protective covering of rice grains. Rice husk ash (RHA) is primarily composed of silica with its properties and applications largely influenced by the method of combustion. The burning process removes organic components like cellulose and lignin leaving behind silica-rich ash. The high silica content enhances its reactivity and makes it suitable for use in cement-based materials and utilizing RHA also reduces the carbon footprint associated with traditional cement production which is responsible for significant carbon dioxide emissions. Its potential in construction arises from its transformation into rice husk ash (RHA) through controlled burning which enhances its pozzolanic properties making it a valuable supplementary material in concrete production [1].

Rice husk ash's tiny particle size, porous structure, high amorphous silica concentration, and potent pozzolanic reactivity are its main characteristics. RHA particles are finer than cement with high specific surface areas (11–39 m^2/g), and are irregular and porous in structure. High pozzolanic activity due to amorphous silica enabling RHA to react with calcium hydroxide in cement improving strength and durability [2]. The concrete industry has long been associated with serious environmental problems such as waste production, resource depletion and excessive carbon emissions. The use of agricultural waste materials as an additive or partial replacement for common concrete ingredients such as cement and fine aggregates is becoming increasingly popular as a solution to these problems. However, its optimal use in concrete mixes remains under-researched especially concerning its impact on compressive strength and workability.

Several studies suggest that agricultural waste materials such as rice husk can influence concrete properties such as workability and compressive strength. Concrete incorporating RHA shows improved compressive strength, flexural strength and bond strength particularly at lower replacement levels [3]. One study showed that the workability of fresh concrete decreases with the addition of Rice Husk Ash (RHA) as a partial replacement for cement. This reduction in workability is observed across various replacement levels, impacting the ease of mixing and placing the concrete [4]. Njagi et al proved that workability improves with 10% RHA and decreases with further addition [5].Other past research also showed that workability decreases as the percentage of Rice Husk Ash (RHA) increases in concrete mixtures. Optimal workability is achieved with a 10% replacement of cement beyond which more water is required for desired consistency [6]. One study also found that a 10% RHA replacement resulted in a significant increase in compressive strength, making it suitable for applications such as road pavements [7]. Another study corroborated this finding, noting that 10% RHA replacement in engineered cementitious composites (ECC) provided the best compressive strength at 28 days [8]. Overall, it remain unclear whether 10% RHA is the optimum partial replacement of cement as most of past research was conducted in bigger range of RHA percentage. This study focus on the research gap by the past research by investigate on the smaller range of RHA percentage which were 8%, 9%, 10%, 11% and 12%.

The objective of this study is to determine the degree of workability of fresh concrete and to evaluate the compressive strength of the concrete. For this purpose, slump test was used to measure the degree of workability while compressive strength was evaluated by testing of concrete cube after 7 and 28 days of curing using Universal Testing Machine (UTM). 36 concrete cubes of 100mm×100mm×100mm was cast and then tested to obtain the result.

2. Methodology

It shown an outline of the overall work process that need to be carried out in order to achieve the objective of the study. It included every aspect which were sample and materials preparation, equipment used, the process and the laboratory testing that was conducted. Figure 2.1 below show the flowchart of this study.

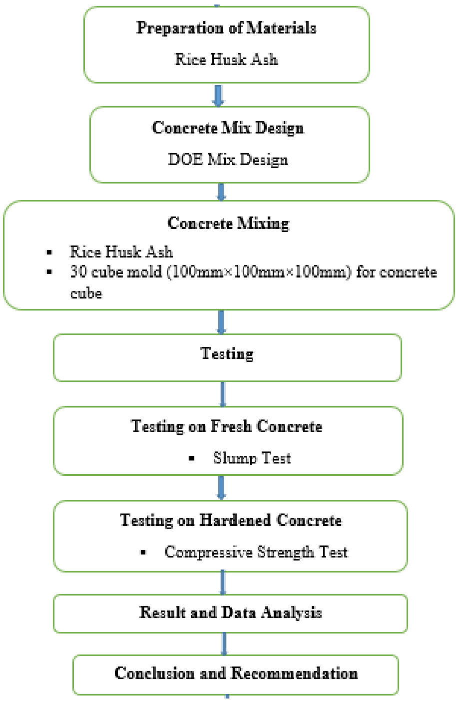


Figure 2.1 *Flowchart of study*

2.1 Mix Design

Concrete mix design is the process of finding the right proportions of cement, sand, and aggregates for concrete to achieve target strength in structures. The DOE method is used to design a concrete mix in accordance with the British DOE mix design method. DOE method help to calculate the exact amount of materials required to produce $1m^3$ of concrete. This design helps to determine the appropriate amount of concrete materials including weight of cement, coarse aggregates, sand and water. It was expressed in kg/m^3. Table 2.1 show the concrete mixing proportion.

Table 2.1 *Concrete mixing proportion*

Properties for trial mix of 0.001 m³						Cube Sample	
Specimen	Cement (kg)	RHA (kg)	Fine Aggregate (kg)	Coarse Aggregates (kg)	Water (kg or L)	7 days	28 days
0% RHA	2.649	0.000	3.454	7.688	1.404	3	3
8% RHA	2.437	0.212	3.454	7.688	1.404	3	3
9% RHA	2.411	0.238	3.454	7.688	1.404	3	3
10% RHA	2.384	0.265	3.454	7.688	1.404	3	3
11% RHA	2.358	0.291	3.454	7.688	1.404	3	3
12% RHA	2.331	0.318	3.454	7.688	1.404	3	3

2.2 Preparation of specimen

Cube mold is used to produce concrete cube for the testing of concrete. Cube mold with dimension of 100mm×100mm×100mm was used. The mixture proportion of the concrete consists of different percentages (8%, 9%, 10%, 11% and 12%). Concrete cube was produced by pouring the concrete mixture into the cube mold shaped. Before pouring, the inside of cube mold been applied with oil so that the hardened concrete will easily be removed when hardened. The iron rod was used to eliminate the air bubble in the concrete. The concrete cube was removed from mold after 24 hours in room temperature. The concrete cube was cured in curing tank for 7 and 28 days.

2.3 Materials

The rice husk ash (RHA) was purchased from online app called Shopee. The rice husk ash was then would be grinding using rice ball machine to produce more small and cement like particles to be used as partial cement replacement for 8%, 9%, 10%, 11% and 12% ratio of RHA. The cement used for this study was Ordinary Portland Cement (OPC). Two types of aggregates was used which were fine and coarse. Coarse aggregates are particulates that are greater than 4.75 mm while fine aggregates was sand that are less than 9.55mm in diameter. The water acted as bind to bound together the rice husk ash, cement, sand and coarse aggregates to form concrete mix.

2.4 Procedure for Slump Test

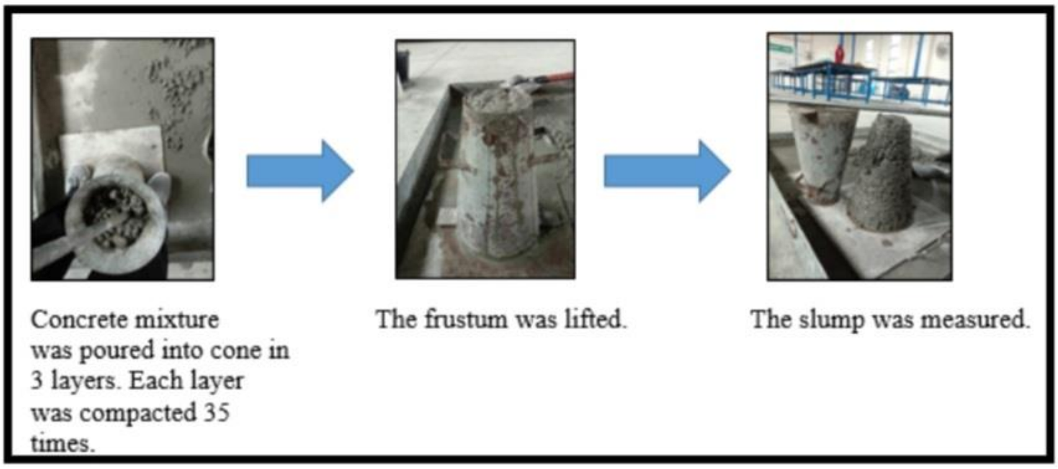
The slump test is a means of assessing the consistency of fresh concrete. It is used indirectly to check that the correct amount of water has been added to the mix. . The test was based on the standards practice in BS EN 12350-2:2009 (Testing Fresh Concrete – Slump Test). Below show the sequence of procedure:

a) Concrete mixture was poured into cone for 3 layers. Each layer was compacted 35 times.

b) After compaction, the frustum was lifted leaving a pile of concrete that settles or 'slumps' slightly.

c) The inverted setting cone is placed on the ground as a reference.

d) The slump was measured.



2.5 Procedure for Compressive Strength Test

Compressive strength is the ability of a material or structure to support the loads applied to its surface without cracking or deflection. A material under compression tends to reduce the size, while in tension, size elongates. American Society for Testing Materials (ASTM) C39/C39M provides standard test method for compressive strength of cube concretes specimen. Compressive strength achieved by concrete at 7 days is about 65% of the target strength. Below show the sequence of procedure:

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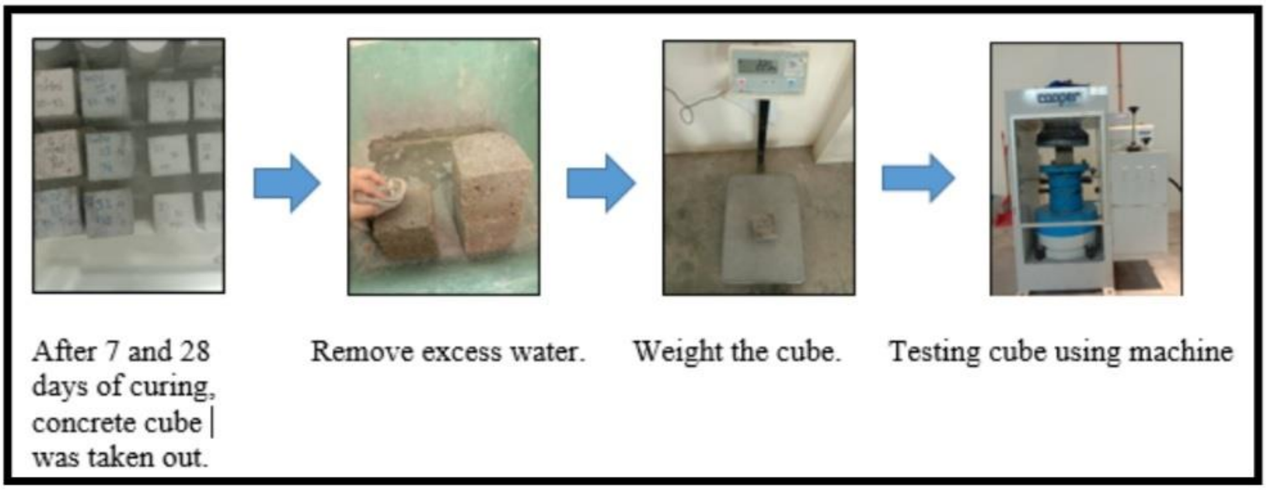
a) After 7 and 28 days of curing, concrete cube was taken out from curing tank.

b) The concrete cube was dried by wipe off excess water.

c) The cube was weighed after curing.

d) Used compression testing machine or UTM to get the load of the concrete cube until it fail.

e) The data for each concrete cube was recorded.



3. Result and Discussion

The study main objective was to determine the degree of workability and evaluate the compressive strength of concrete. The performance for partial replacement of rice husk ash (RHA) of 8%, 9%, 10%, 11% and 12% in cement for concrete mixture was analysed for its workability and compressive strength test.

3.1 Slump Test

Table 3.1 below show the slump test result for different ratio of RHA.

Table 3.1 *Slump test result*

Samples	Collapse Height (mm)	Type of Slump	Degree of Workability
RHA 0	54	True slump	Medium
RHA 8	48	True slump	Low
RHA 9	46	True slump	Low
RHA 10	38	Shear slump	Low
RHA 11	36	True slump	Low
RHA 12	34	True slump	Low

According to Table 4.1, the result shows slump test that was conducted with different percentage of rice husk ash (RHA) as partial replacement of cement in concrete mixture. Sample RHA 0, 8, 9, 11 and 12 was classified as true slump while sample RHA 10 was classified as shear slump. Sample RHA 8, 9, 10, 11 and 12 have low workability ranging from 34 mm to 48 mm while sample RHA 0 has medium workability. Sample RHA 12 shows the minimum collapse height while RHA 8 shown the highest value of collapse height of 48 mm. This is because RHA is a very fine and porous pozzolanic material that absorbs water then reducing the free water available in the mix thus making it stiffer and reducing the collapse height.

Concrete mixes with low workability can be difficult to work with in actual construction which can result in problems like incomplete compaction and could compromise the structure's ultimate strength and longevity. How workable a concrete mix depends on a number of factors including water content, mix proportions, aggregate characteristics and additive application. A rough texture and surface flaws may result from low workability which makes it difficult to obtain a smooth and even surface finish. Low workability concrete is frequently stiff and takes a lot of work to properly compact. The density and strength of the concrete can be decreased if air pockets are trapped in the mix due to improper compacting. Managing low workability concrete requires more work to pour and finish that can lead to slow down the construction and raise labor expenses. Segregation in which heavier aggregates separate from the mortar and produce an uneven mix can also be caused by low workability. This can weaken the concrete and create weak spots in the structure. Contractors usually aim for 75 to 100 mm for normal reinforced concrete. Adjustments in mix design are necessary at higher RHA content to maintain uniformity and performance in practical applications.

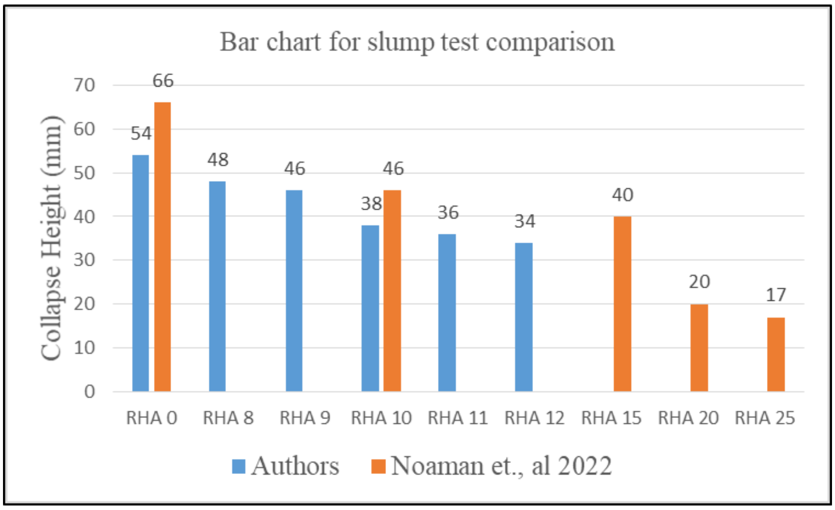


Figure 4.1 *Bar chart for slump test comparison*

Based on the results of the slump test in Figure 4.1, it can be concluded that the slump or collapsed height decreased as the percentage replacement increased. Similar result were obtained based on the research by Noaman et al [9]. It may be because of the fact that RHA absorbed more water because of its absorptive nature which is derived from the cellular structure of RHA particles according to Noaman et al [9]. This proved RHA absorbs water and reduces workability that required more water or admixtures to maintain the slump conditions.

3.2 Compressive Strength Test

Figure 4.2 shows the data of concrete cube obtained after 7 days and 28 days of curing.

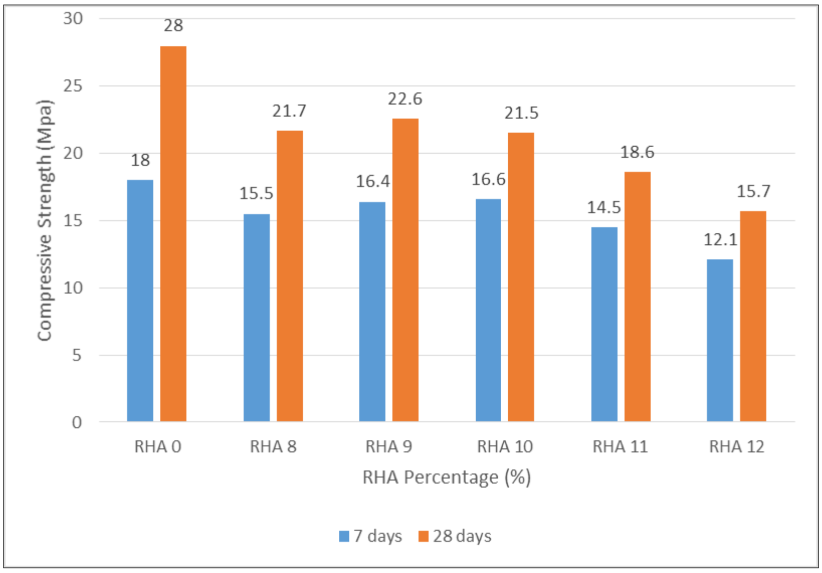


Figure 4.2 *Bar chart for compressive strength test*

For M25 grade concrete, the expected compressive strength after 7 days of curing is around 17Mpa while after 28 days of curing is 25 Mpa. For 7 days aged concrete, sample RHA 0 achieve the expected strength of 18Mpa. Sample 8, 9, 10, 11 and 12 did not meet the expected strength with a compressive strength value of 15.5Mpa, 16.4 Mpa, 16.6 Mpa, 14.5 Mpa and 12.1 Mpa. From this, it showed sample 10 achieved the highest strength but still not reached the targeted strength of 17 Mpa at 7 days aged concrete. These results show a slight reduction in early strength with the partial replacement of RHA. However, the 9% and 10% partial replacements show only a modest decrease in strength compared to the control sample suggesting that RHA up to 10% does not drastically reduce early strength. After 28 days, the compressive strength of all samples increased consistent with normal concrete hydration behavior. Then, for 28 days aged concrete, sample RHA 0 achieve the expected strength of 28 Mpa. Sample 8, 9, 10, 11 and 12 did not meet the expected strength with compressive strength value of 21.7 Mpa, 22.6 Mpa, 21.5 Mpa, 18.6 Mpa and 15.7 Mpa. The results indicate that concrete with up to 9% RHA replacement achieves compressive strengths that are reasonably close to the control sample.

The 9% RHA in particular performed the best among the RHA samples with a 28-day strength of 22.6 MPa suggesting that it can be an optimal replacement level under the test conditions. The compressive strength drops more noticeably when higher than 10% RHA partial replacement as used. At 12% RHA, the strength fell to 15.7 MPa around 44% lower than the control sample. This result attributed from the reduced availability of calcium hydroxide and insufficient cement matrix to sustain the strength development. From the comparison based on 7 and 28 days aged concrete, it shown that only sample 0 also known as control sample that achieved the targeted strength as it not partial replaced with RHA which made the concrete stronger than the sample containing RHA.

According to research by Wang et al [10] in recycled aggregate concrete, the ideal replacement ratio of 10% rice husk ash for cement increases compressive strength by 0.4% and 4.9% with rice husk ash making a greater contribution to strength improvement than natural aggregates. Despite the fact that many research have shown that using 10% rice husk ash (RHA) in partial replacement of cement produces the best results in terms of workability and compressive strength, the results of this study did not support that finding. At 10% RHA partial replacement, the compressive strength was underperformed below the control sample and fell short from the targeted Grade 25 which was 25 Mpa. Several factors in the RHA's physical and chemical characteristics including its fineness and burning circumstances which are known to have a major impact on pozzolanic activity could be the cause of this result. It also can be due to excess amount of water during mixing of concrete.

3.3 Relationship between workability and compressive strength of concrete

Based on the results, there is no direct linear relationship between degree of workability and compressive strength. This is because workability is the ease of mixing, placing, compacting and finishing freshly mixed concrete without bleeding or segregating. The slump test is used to measure it. High workability mean easy to place and compact while low workability make it a challenge to manage. The compressive strength is the ability of a material or structure to support the loads applied to its surface without cracking or deflection. The water-cement ratio is the only key link between workability and strength. Increasing water content can improves workability but reduces strength while lower water content increases strength but reduces workability. A concrete mixture workability is improved by adding more water because it lower the internal particle friction which makes the mixture simpler to handle, place and compact. But as the excess water evaporates during curing, the same increase in water results in a larger water to cement ratio which produces more porosity. The internal structure of the hardened cube concrete is weakened by these pores which then lowers the concrete's compressive strength. In conclusion, there need a good balance between them to achieve good workability and adequate strength for the concrete.

4. Conclusion

All the tests done following the standard to meet the objectives of the study. Two tests was conducted which were slump test and compressive strength test. The objectives of the study were achieved for the workability of fresh concrete and strength of concrete that partially replaced cement with rice husk ash (RHA). The optimum percentage of partially replace cement was conducted based on 8%, 9%, 10%, 11% and 12% of RHA with 0% as control samples. The outcome of the study shown the values of compressive strength based on different percentage of RHA and slump values for the tests.

Table 4.1 *Optimum RHA percentage as partial replacement of cement*

No	Test	`Data	RHA (%)
1	Slump Test	46 mm	9
2	Compressive Strength	22.6 Mpa	9

In conclusion, the objective for this study was achieved. The slump value of 46 mm for RHA 9 can be used for foundations with light reinforcement or pavements consolidated by hand operation vibrators. For examples beams, walls and columns structures. The optimum compressive strength of the concrete of partial replacement of cement was RHA 9 with 22.6 Mpa. The partial replacement of RHA delivers a balanced performance, offering sustainability and also reduced cement consumption while meeting most structural requirements. Rice husk ash (RHA) is a carbon-neutral material that releases significantly less carbon dioxide during production compared to cement. Its use as a supplementary cementitious material can helps reduce environmental impact and promotes sustainability in concrete manufacturing.

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Conflict of Interest

Nurul Izzati Othman and Mohd Sufyan Abdullah declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

Nurul Izzati Othman and Mohd Sufyan Abdullah confirm contribution to the paper as follows: ***study conception and design:*** *Nurul Izzati Othman, Mohd Sufyan Abdullah;* ***data collection:*** *Nurul Izzati Othman;* ***analysis and interpretation of results:*** *Nurul Izzati Othman, Mohd Sufyan Abdullah;* ***draft manuscript preparation:*** *Nurul*

Izzati Othman, Mohd Sufyan Abdullah. All authors reviewed the results and approved the final version of the manuscript.

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