Effect of Rice-Husk as Replacement Cement on Mechanical Properties Concrete

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ABSTRACT

The cost of producing concrete has increased, and its effects on the natural environment have become apparent. The ideal solution is to use agro-waste material instead of cement in concrete. This research aims to determine how well RHA works as a cement substitute. At increments of 5%, 10%, and 15%, rice husk was applied in substitute of cement. Compressive and flexural tests were performed on a 100 mm x 100 mm x 100 mm cube and 100 mm x 100 mm x 500 mm prisms with varying percentages of RHA substitution. Findings show that the highest control sample has a compressive strength of 49.83 MPa while t The compressive strength began to drop at 5% RHA substitution. The compressive strength decreased as the percentage of RHA used increased from 10% to 15%. The flexural strength data shows that the 10% RHA has a maximum of 4.90 MPa. The lowest value is 3.85 MPa, and it is only seen from 5% of RHA. Thus, it can be inferred that an RHA replacement level of 5% in cement yields a tremendous increase in compressive strength.

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Introduction

Cement, fine and coarse aggregate, and water are the most expensive of the concrete's standard components. This has led to a recent hike in the cost of concrete, a necessary used construction material. As the building industry expanded in Malaysia, so did the demand for cement, which in turn fueled the growth of infrastructure development in the country.

Due to its functions as a binder, cement is the primary component used in the production of concrete. Cement manufacturing is consequently resource-intensive, costly, and environmentally damaging [1]. Worth to mention that Ordinary Portland Cement (OPC) is the most common kind used in the major construction sector. Unfortunately, the main primary constituent of cement is limestone which is a non-renewable resource. Hence, cement production is highly-priced, uses a lot of energy, and depletes natural resources [2]. It is a great concern to the environment as long-running, extensive mining will eventually cause depleted sources of limestones. In addition, the cement is made up of components such as silica, alumina, and magnesia as well as iron oxide. Besides, the negative impact of this kind of cement is also degradative to the environment due to the high emission of carbon dioxide. It was estimated that around 7% of the world's carbon dioxide output emanates from the cement industry [3].

Auspiciously, developments in concrete technology are making it possible to lessen carbon dioxide emissions caused by the production of cement and to substitute industry and agricultural waste for concrete in construction projects. Since a few decades, cement-replacement materials like fly ash and powdered granulated blastfurnace slag have been routinely used to reduce the amount of cement used [4]. Pursuant to previous studies, rice husk can be burned to create rice husk ash (RHA). The physical and chemical composition of RHA is following the standards for mineral admixtures for it to perform as the substitute [5]. Based on earlier research, evidence suggests that the mechanical properties of concrete can be enhanced by adding RHA in the right proportions. Regarding the manufacture of concrete, because of its high content of silica, RHA is regarded as a highly reactive pozzolanic material [6]. Therefore, rice husk is one of the potential answers to the problem of mitigating the depletion of limestone.

The production of harvestable goods in agriculture results in the generation of a significant volume of waste. Straws, bagasse, and husks are the three most common types of biomass products that come from plants or crops. Burning agricultural waste in the open field is a typical method of disposal for farmers. Ashes have the potential to spread into neighbouring areas, which can lead to environmental and landfill problems. On the other hand, the practise of dumping rice husks in landfills can occupy a substantial amount of space and is a major contributor to environmental damage [2].

Ash from burning rice hulls for energy production is a common agricultural byproduct known as rice husk ash (RHA) [7]. Another way to produce RHA is to employ boilers, where the paddy can be directly burned or gasified to produce the fuel [8]. Both methods have the potential to extract RHA from paddy. When compared to other agricultural wastes that can be used in the building sector, rice husk has shown the best performance as a supplemental cementitious material (SCM) due to the high silica content of the ash [9].

Production of a rice paddy in Malaysia increased from 3 million tonnes in 2015 to 4.6 million tonnes in 2018 and 6.1 million tonnes in 2020 [10]. Agricultural waste may be easily obtained due to global production on a huge scale, making it a cost-effective alternative to more conventional building materials. The waste can be used in place of traditional materials because it is abundantly produced all over the world and hence easy to acquire. The rice husk, which originates from the outermost layer of paddy grain, however, will be dumped or burned, which will add to existing disposal problems and environmental worries [11]. Therefore, using rice husk in replacement of concrete might be one step toward finding a solution that addresses the issue. This aids the country by reducing waste disposal costs and protecting the environment.

One of the distinguishing features of this material is its high concentration of amorphous silica, which, when combined with portlandite in cement, can lead to the creation of a pozzolanic phase. In addition, RHA could be utilised to enhance the bond between different concrete mixtures by filling in the spaces between the cement particles [12]. By infiltrating voids between cement grains, RHA is capable to strengthen bonds in various concrete combinations [13]. The overall performance characteristics of the cementitious product are enhanced through the use of this pozzolanic method at later ages. On the other hand, RHA is used to replace cement partially, a considerable reduction will be made to the amount of CO_2 annually discharged into the environment [14]. Another approach for cutting costs on cement and lime is making use of RHA to cut down on the overall quantity of binders that are needed for a variety of construction projects. RHA-blended concrete has been reported to have lower air permeability and chloride penetration, lower alkalisilica expansion, and higher sulphate and acid resistance, among other qualities [14].

Moreover, when compared to the other types of ashes that were tested, the RHA concrete had the highest normalised compressive strength. The prior research indicates that a replacement level of 10-20% RHA in concrete is optimal [15]. However, RHA concrete was found to have normalised compressive strengths that were nearly 1.2 times higher than those of the control concrete. This is because elevating the proportion of amorphous silica in the RHA formula significantly improved both pozzolanic performance and concrete properties.

In the study, rice husk waste at 5, 10, or 15% were used to supplant portland concrete for compressive and flexural consistency. The objective of this research is to provide information on the utilization of RHA as a supplementary cementing material for producing green concrete. Additionally, to the effects of the percentage of RHA as cement replacement and water-cementitious materials ratio on the mechanical properties investigated, the properties of the RHA concrete were also compared with those of the control portland cement concrete and the concrete containing silica fume. The outcome of this study benefit in the field of green concrete.

Experimental Work

Concrete mix design commonly uses form of dimensions or ratios such as 1:2:4, respectively representing the proportions of cement, fine aggregates, and coarse aggregates. The ratio is either determined by weight or volume. Although in terms of its simplicity of expression, this concrete mix design system has an advantage. However, it will cause a disruption when describing the effect of the mixing measurement on the concrete features. This is related to the importance in defining the amount of cement needed to cast a given concrete size. Thus, using the typical mix concrete layout sheet to measure the concrete mixing percentage is the most ideal way to specify mixing parameters for each individual material engaged in concrete mixing in terms of volume. Moreover, by measuring specifically the mixing percentages required for concrete mixing, the waste of materials typically occurring will be minimized.

Material preparation

Cement

For this experiment, four different series of RHA replacement concrete were constructed: a control series, and RHA replacements of 5%, 10%, and 15%. The cement that was used throughout this experiment was acquired from Tasek Cement, which fulfills the requirements outlined in MS EN 197-1:2007 [16]. These tests were conducted with a 42.5-strength class of Ordinary Portland Cement (OPC). The Tasek Cement is obtained from concrete laboratory, UiTM Shah Alam.

Rice husk ash

Rice husk ash is generated by burning rice husk in a regulated manner. Having a high SiO_2 concentration after being properly burned, it can be applied as an additive in concrete. During the hydration process, calcium hydroxide crystals form in concrete, and the amorphous silica in RHA reacts favourably with these crystals. The C-S-H gel that is created as a by-product of the concrete hydration can be implemented to fill the porous structure. This is possible since the gel's viscosity is lower than that of water. Rice husk ash is operated as an alternative to cement in concrete.

The rice husk is obtained from a local source of rice paddy. Then, the rice husk is dried and placed in the furnace until it changes into ash. The ash are collected from the furnace and grounded until achieving a specific size is needed.

Aggregate

Suitable selection of optimum coarse aggregate size is essential in concrete mix design as it affects concrete strength. In addition, the coarse aggregate should be cleaned and free of chemicals that can lead to concrete degradation. Crushed stones are typically coarse aggregates used for concrete mixing. The material that can be sieved through a 4.75 mm screen contains fine aggregates. Quarry coarse aggregates with a nominal size of 10 mm were selected for this study. Coarse aggregates is obtained from Kajang rock quarry and fine aggregate obtained from concrete laboratory, UiTM Shah Alam.

Superplasticizers

A chemical addition from the MasterGlenium Sky 8333 group was incorporated into the concrete mixing process to decrease the water-cement ratio, enhance the concrete’s formability, and strengthen its strength. MasterGlenium Sky 8333 obtained from online purchase bmd.asia.

Design mix

There were four different RHA mixture ratios created. The concrete mixtures used in the casting process include a control mixture and variations with 5, 10, and 15% RHA, respectively. Table 1 outlines the relative amounts of RHA and materials incorporated into the concrete mix. Upon continuing to the casting process, the fresh concrete is then tested to assess its workability using the slump test. In addition, the vibrating table is being used to vibrate the mould to ensure that the concrete is evenly compacted while minimizing the air void produced in the concrete.

Hence, OPC was utilised with a constant water-cement ratio of 0.54. This study consisted of 36 total samples, consisting of 36 different prism sizes (100 mm x 100 mm x 500 mm) and 36 different cube specimens (100 mm x 100 mm x 100 mm). For further works, the tests comprised both a compressive and a flexural measure of the strength. The slump test was carried out to provide data supporting the applicability of fresh concrete. Curing times in water ranged from 7 days to 14 days to 28 days for each specimen.

Table 1: Different percentages of rice husk ash with the material

Mixture	Cement (kg/m^3)	RHA (kg/m^3)	Fine aggregate (kg/m^3)	Coarse aggregate (kg/m^3)	Water (kg/m^3)	SP (1% of cement weight) (ml)
Control	16.13	0.00	33.05	40.38	8.72	168.00
5% RHA	15.33	0.81	31.47	38.45	8.31	147.00
10% RHA	14.52	1.61	31.47	38.45	8.31	147.00
15% RHA	13.71	2.42	31.47	38.45	8.31	136.50

Experimental apparatus and procedure

Compressive test on the specimen

A component or structure's compressive strength is its capacity to resist cracking or surface deformation under stress. The concrete shrinks under compression and expands under strain. Additionally, compressive strength testing relies heavily on load rate. The observed strength increases with increasing loading rates. Slow loading rates have been suggested to initiate more subcritical cracking or to bring about the emergence of creep that modifies the amount of strain at a given load. Insight regarding concrete characteristics can be gained through this assessment. By conducting this check, it will be possible to ascertain whether or not the concreting activities have been performed correctly. This evaluation was carried out following the standards laid out in BS EN 12390-3:2019 [17].

Cube test uses 100 x 100 x 100 mm mould relying on the aggregate size used. The concrete is poured into the mould in three separate levels; after each addition, the table vibrates to compact the concrete. Cement pastes were applied to the top of the cubes and spread evenly to create a flat, level surface. After twenty-four hours, the cubes were taken from the moulds, and the curing tank was loaded to begin the curing process. The cubes are evaluated with a compression machine after 7, 14, and 28 days of curing, and thus were tested at the proper angles to the casted position. The load was imposed incrementally from this point on until the cube broke. When calculating the compressive strength of concrete, the failure load from the test must be divided by the cube's surface area. Figure 1 depicted the process of compressive test.

Flexural test on the specimen

Flexural strength, which can also be referred to as modulus of rupture, is the ability of a concrete to resist deformation as a result of bending. This test method covers the determination of the flexural strength of concrete by the use of a simple prism with four-point loading. The maximum flexural loads were determined using the UTM-1000 at the Concrete Laboratory, UiTM Shah Alam, Selangor. Remove the prism from the curing prosses for 7,14 and 28 days from water tank and test while they are still wet. For this test, will be tested using 3 specimens each. Based on the peak load, the peak flexural stress within the prism is calculated. The significance of using 3 specimens for each period is to obtain the average flexural strength values The standard that has been use can fullfill the requirement Figure 2.

Figure 1: The specimen after compressive test

Two-point loads, 100 mm apart, are applied to the third points along the span of a simply supported concrete prism. In accordance with BS EN 12390-5, the load is steadily raised at a rate of 0.5 mm/min until flexural failure occurs. Prism size of 100 mm x 100 mm x 500 mm was used in this study. Figure 3 depicted the process of Flexural strength test.

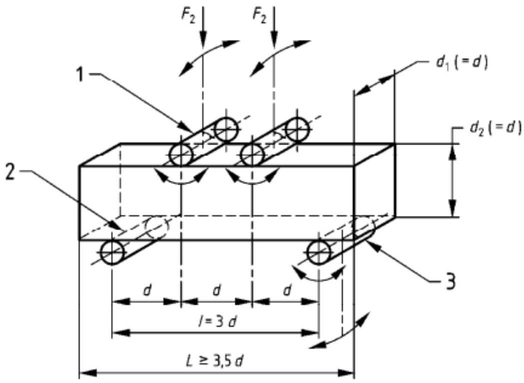

Figure 2: Arrangement of loading of test specimen (BS EN 12390-5) [18]

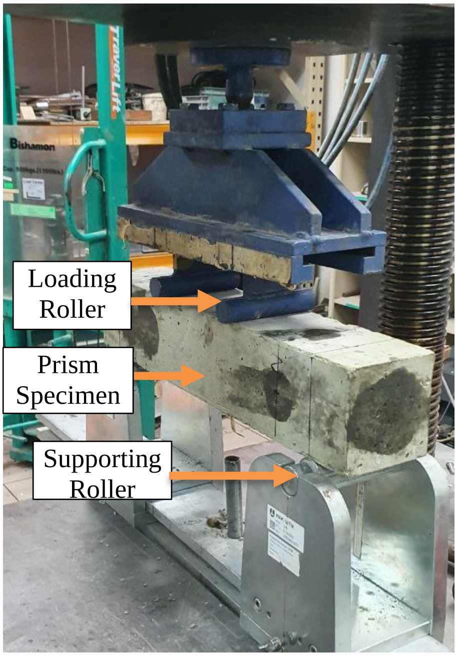

Figure 3: The specimen before flexural test

Results and Analysis

Figure 4 displays the changes in compressive strength that took place 7, 14, and 28 days after the RHA was replaced. During 7 days all RHA mixed concrete compressive strength is very low compared to control concrete. This might be due to the silica and the reduction of calcium hydroxide in the concrete mix not being able to enhance the concrete strength. These results indicate that the higher rate hydration process for normal mixed concrete compared to the concrete that contained pozzolanic material RHA starts at a later age and becomes significant when a considerable amount of $Ca(OH)_2$ is produced as a hydration product of cement. RHA reacts with cement hydration product $Ca(OH)_2$ to produce a secondary C-S-H gel. It happens because of the effect of the pozzolanic reaction which usually manifests at a later stage [19]-[20]. At 28 days, the strength of the control concrete reaches 49.82 MPa. After 28 days, the strength was 35.15 MPa when RHA was used for 5% replenishment. It was discovered that the optimal value of RHA significantly lowers the strength of concrete.

The result shows that the compressive strength of RHA concrete reduced as the percentage of RHA replacement increased and the concrete did not significantly influence the later age strengths. Results by [21] are in line with the present study, indicating that large amounts of RHA have an adverse effect and reduced the strength of concrete. This might be due to the lower calcium hydroxide content that has been reduced with the replacement of RHA in the mixes. Nevertheless, the strength of concrete with the replacement of cement by up to 15% RHA manage to attain the target strength of 30 MPa.

Meanwhile research [22] found that there is reduction in compressive strength at earlier ages with the increasing RHA content in concrete. In addition, superplasticizer (SP) improves the compressive strength of concrete with 5% and 10% cement replacement by RHA. SP is used to develop concrete with high early strength. It shows that the effect of SP can help to increase the compressive strength of the concrete. Thus, the increase in SP dosage parallel with the increment of RHA content contributed to the development strength in concrete. Hence the overall result of the compressive strength of concrete shows the different values from one another as the different dosages of SP are used as well RHA content.

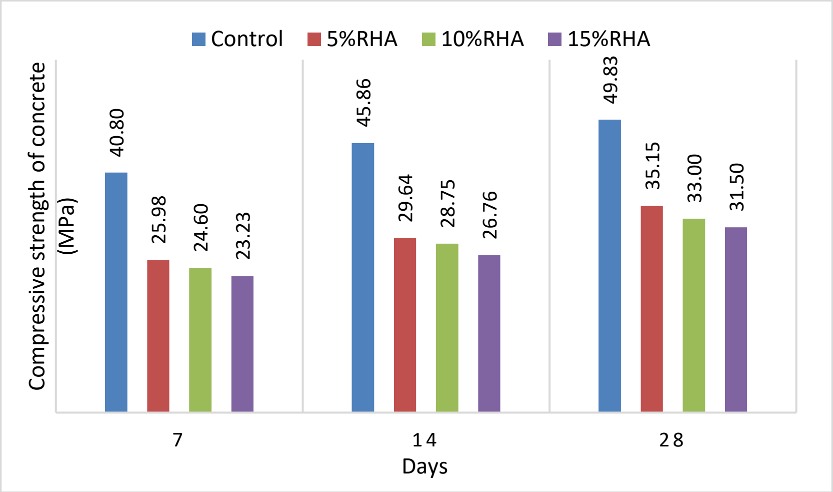

Figure 4: Compressive strength of concrete at 7, 14 and 28 days

Figure 5 displays the flexural strength at the age of 7, 14 and 28 days for different mix proportions. Flexural strength at 7 days of curing due to pozzolanic and filler effects of 5%, 10% and 15% RHA concrete is less significant than the hydration effect of control concrete. However, at 28 days of curing 10%, 15% RHA gained additional flexural strength than control concrete due to pozzolanic reaction. Meanwhile, the lowest flexural strength was for 5% RHA concrete with a value of 3.85 MPa less significant at later ages when compared to the hydration effect of control concrete

When 10% RHA is used as a replacement for the OPC, the concrete gains a maximum strength of 4.90 MPa. In comparison to the standard concrete specimen, the value represents a 6% increase in strength.The 10% RHA has the highest strength because due to the higher specific area of the RHA which accelerated the pozzolanic reaction of reactive SiO_2 in RHA with CaOH to produce more C-S-H gel. Decrease portlandite content of the matrix can lead to the improvement of the pore structure of the concrete matrix, which is due to the high pozzolanic and compatibility of RHA with cement. RHA made concrete pore structure finer, and hence, reduced the volume of large pores and also showed a reduction in the total porosity in the concrete. RHA also acts as filler causing the foamed concrete to become denser while retaining its unique low density. The gel produced then fills up all possible voids in the sample and it will increase the flexural strength of the sample.

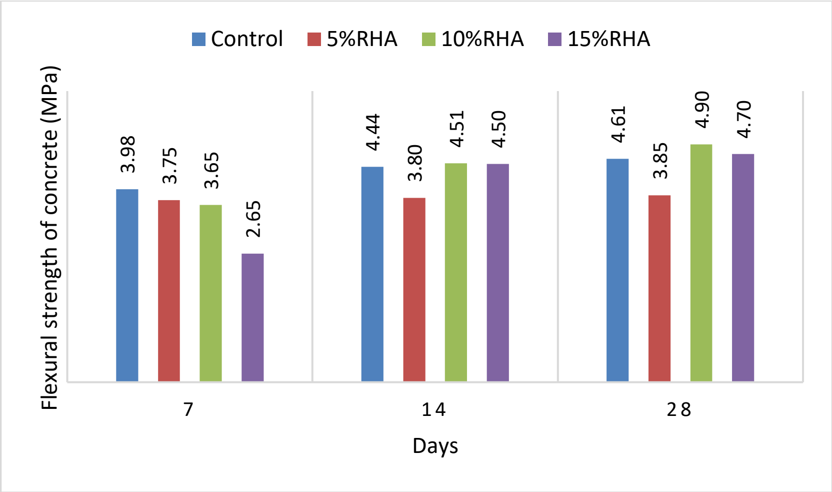

Figure 5: Flexural strength of concrete at 7, 14 and 28 days

When the amount of RHA in concrete increases by more than 10% relative to its replacement with cement, the strength of the concrete decreases. This reveals that the RHA's behaviour has been altered due to the presence of excessive silica in the bonding and material. Based on the overall result of flexural strength test of the concrete, the result shows an increase. The concrete that contains higher percentage of RHA, increased gradually compared to the percentage of control concrete. However, all the result of flexural strength of the replacement concrete has a higher value compare to control sample. It proven that RHA can be use to replace cement and help the concrete to improve the strength.

Previous research [23] stated that the flexural strength of concrete specimens containing ordinary RHA is comparable to that of control mix specimens, while concrete containing RHA has much higher strength. Partial replacement with RHA improves flexural properties and durability by creating strong bonding that allows concrete to distribute loading during bending deflection. A study by [24] showed that optimal flexural strength can be achieved with 10% replacement of RHA. However, the same study also found that using 15% replacement of RHA resulted in a gradual decrease in flexural strength.

The pozzolanic products produced by RHA help to improve the bonding between cement mortar and aggregate. As the percentage of RHA replacement increases, there is a gradual increase in the flexural strength of rice husk ash concrete up to nearly 10% replacement, after which it decreases.

Conclusions

The following are some of the significant conclusions that can be drawn from this study:

- The results of a test to determine the material's compressive strength have been collected and appropriately tabulated. Research indicates that a concrete mixture containing 5% RHA adds the most to the average compressive stress, at 35.15 MPa.
- The concrete's compressive strength exceeded that of mixes made without RHA. This implies that the RHA qualities do not assist in enhancing the blended cement concrete's compressive strength.
- The compressive strength of concrete was significantly impacted by the RHA used. The compressive strength of concrete drops from 5% to 10% and 15% after RHA replacement. After 28 days, 5% RHA concrete reportedly has a 23% lower compressive strength than control concrete.
- While compared to the strength of control concrete after 28 days, the flexural strength of 10% RHA concrete exhibited a 6% increase in its strength.
- The percentage of RHA that should be added that yields the best result in this investigation is 5%. The findings of the compressive strength test show that on day 28, the RHA addition of 5% yields the highest strength. In contrast, adding 10% or 15% RHA is not recommended due to subpar results in terms of strength. Thus, it is more appropriate to incorporate 5% RHA into concrete mixes.
- This study will benefit mostly the material researcher that agricultural waste can be used as replacement cement in concrete. The researcher

can get information on using RHA as replacement cement and superplasticizer in concrete mixing that can be used in their research. Researchers can know about agricultural waste, which is RHA has many advantages in the construction industry. Researchers can use this study as a baseline and reference to other researchers.

Contributions of Authors

The authors confirm the equal contribution in each part of this work. All authors reviewed and approved the final version of this work.

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Conflict of Interests

All authors declare that they have no conflicts of interest.

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