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Compressive Strength of Concrete using Rice Husk Ash Produced at Different Temperatures

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Abstract

This study focuses on the optimization of the burning temperature of furnace-incinerated rice husk ash (RHA) into a concrete mix design. The primary objective of this study is to investigate the optimum proportion of incineration temperature required to develop an amorphous silica from rice husk wastes and to determine the compressive strength of blended cement replaced partially at the ratio of 5%, 7.5%, 10.0%, and 12.5% of RHA, incinerated at temperatures of 600 °C, 700 °C, and 800 °C. The experimental test specimens, consisting of concrete cubes, were prepared and tested after 7, 14, and 28 days of water curing. The pozzolanic reactivity of RHA highly depends on the silica form. The silica form in the RHA is analyzed by chemical composition analysis and x-ray diffraction analysis based on the incineration period to decide if it is in the amorphous or crystalline form, with the identifying sample having a greater influence on the compressive strength. This study shows that the presence of RHA in concrete tends to improve compressive strength, especially at the early stages of curing, and the optimum replacement of cement with RHA in the concrete was 7.5% at the incineration temperature of 700 °C.

Keywords: Rice husk ash, pozzolan, incineration temperature, compressive strength

1. Introduction

The demand for cement is rapidly growing due to intensive development and construction worldwide. Over 5% of global CO2 emissions are credited to Portland cement production. Data from the U.S. Geological Survey shows that the world cement production in 2011 was 3.6 billion tons, and in 2012, the production was 3.7 billion tons (USGS, 2015). To mitigate the issue of cement limitations (OPC), the cement can be partially replaced with green materials that have pozzolanic characteristics. At present, a number of green products have been studied for the replacement of cement in concrete, like fly ash, groundnut shell ash, and palm oil fuel ash.

Rice husk is the outer cover of paddy, and it covers 20–25% of the paddy weight. In general, a hundred million tons of rice husks are produced annually and create a disposal problem. As a by-product extracted from the rice mill, RHA has a minimum or no commercial value, and commonly, it will end up as a waste that generates disposal and health problems for the inhabitants. Generally, the rice husk will be burned in the open air or sent to landfills, but both methods create enormous CO2 emissions into the atmosphere (Kartini, 2011).

Rice husk ash (RHA) is a highly pozzolanic material, and its characteristics of non-crystalline silica and the high specific surface area of RHA are responsible for its high pozzolanic reactivity. After the incineration of rice husk, about 20% of its weight will contribute to generating rice husk ash (Tashima et al., 2004). The generated RHA contains over 90% silica and can be an economically viable raw material for the production of silicates and silica (Kumar et al., 2013; Zhiliang Z et al., 2016). Furthermore, RHA contains around 85–90%

silica, which is mostly in an amorphous state, and it is a highly reactive pozzolanic material in the production of concrete due to its high silica content (Jamil et al., 2013). Bangwar et al. (2017) carried out a study on developing the amorphous silica appearance in RHA and found that the amorphous silica appeared at 800°C of incineration. However, Xu et al. (2011) found that amorphous silica existed at 600°C of burning in their scientific study. Therefore, this paper is an attempt to review the research depth and directions of the processing incineration temperature as well as the structural nature of the silica produced from rice husk.

The inclusion of a high quantity of replacement of RHA with cement at ratios ranging between 15% and 40% decreases the quality and strength of concrete (Krishna et al., 2016; Bhushan et al., 2017; Habeeb et al., 2010). Moreover, the optimum temperature range for RHA has not been in common agreement since it has been reported by several researchers to be 600°C to 800°C. The present study has been taken up to assess the compressive strength of concrete with rice husk ash (RHA) used to replace cement at different replacement ratios and to investigate the amorphous silica content of RHA after burning at different temperatures.

2. Materials and Test Methods

The aim of this study, as mentioned above, is to investigate the compressive strength of concrete with partial cement replacement with RHA that was produced at different incineration temperatures, as well as to conduct a critical review of previous literature to analyze the chemical composition of RHA and the amorphous silica state of the produced RHA. The materials used and the methods followed for conducting the tests are given in the following sections.

2.1 Materials

YTL Portland Cement, corresponding to ASTM Type I provided by the concrete lab, was used throughout the experimental work. The coarse aggregate was crushed granite with a maximum size of 20 mm. Mining sand with a specific gravity of 2.89 was used as a fine aggregate. Both coarse and fine aggregates were batched in a saturated, dry condition. Supplied tap water was used throughout the study for mixing, curing, and other purposes. The rice husk was collected from a local rice paddy supplier and burned into RHA.

2.2 Preparation of Rice Husk Ash

At the first stage, preparation of rice husk ash (RHA) Rice husk was provided by Dinxings Company, a local mill. Then, to produce ash from the rice husk, the husk is collected to be burned in a muffle furnace, which is designed as an oven in order to burn the rice husk, as shown in Figure 1, which is located in the laboratory. Raw rice husk is to be kept in the incineration furnace for burning at fixed, controlled temperatures of 600°C, 700°C, and 800°C for two hours, respectively. After incineration, it is allowed to cool for 4 hours. The percentage weight of RHA is recorded for reference purposes. According to Tashima et al. (2004), about 20% of RHA can be obtained from the unburned rice husk. After collecting the RHA from the muffle furnace, samples from 600°C, 700°C, and 800°C burning temperatures are separated from each other. The RHA samples are then collected and ground for 30 minutes to a certain fineness by the LA grinding machine.

Figure 1. Muffle Furnace at UiTM Concrete Laboratory Utilized for Rice Husk Incineration

2.3 Concrete Mix and Preparation of Test Specimens

The concrete mix is prepared and designed according to the Building Research Establishment (BRE, 1997). Concrete Grade 30 was chosen to be used for this study. G-30 concrete refers to the tested concrete that will achieve a compressive strength of 30 N/mm2 at 28 days. Cement, sand, and aggregate were taken in mix proportion, which corresponds to the G-30 grade of concrete. 0%, 5%, 7.5%, 10%, and 12.5% of cement were replaced by 6RHA, 7RHA, and 8RHA by weight, and concrete was produced by dry mixing all the ingredients homogeneously. A total of 117 cubic specimens were fabricated and cured in water until testing. According to BRE (1997), the water-to-cement ratio was settled at 0.55 to provide good mechanical strength and adequate workability for the mixtures. The mix proportion of RHA concrete used in the experimental work is shown in Table 1.

The mixing procedure was divided into three stages. In the first stage of cement, fine and coarse aggregates were weighed and mixed by hand until all the constituents were mixed uniformly. In the second stage, the measured amount of cement and the ratio of replacements of RHA with cement were added slowly and uniformly. In the final stage, the measured tap water was added and mixed thoroughly until a homogeneous mix was obtained.

Table 1. Mix Proportions of Material Composition for 1 m^3 of G- 30 Concrete

Mix designation	OPC	R5	R7.5	R10	R12.5
RHA (%)	0.0	5	7.5	10	12.5
w/c ratio	0.55	0.55	0.55	0.55	0.55
Cement (kg/m^3)	340.0	323	314.5	306.0	297.5
Fine aggregate (kg/m^3)	515	515	515	515	515
Coarse aggregate (kg/m^3)	1385	1385	1385	1385	1385
Water (kg/m^3)	160	160	160	160	160

2.4 Compressive Strength Test

A compressive strength test is conducted to analyze the concrete's efficiency in application testing. The compressive strength of RHA concrete will be investigated based on the burning temperatures of rice husk at 600°C, 700°C, and 800°C in order to find which incineration temperature has a better influence on the compressive strength of RHA concrete. The compressive strength testing machine, which is located in a concrete laboratory workshop, will be used to determine the compressive strength of the concrete samples, as shown in Figure 2. The cube test, according to British Standard (BS EN 12390-3:2002), is conducted with the standard dimension of 100 mm × 100 mm × 100 mm.

Figure 2. Compressive Strength Machine at UiTM Concrete Lab

In addition, the weight of the concrete sample is recorded before conducting the test for reference purposes. The platen of the testing machine and the surfaces of the sample are wiped before testing to ensure the accuracy of the data collected. After the sample is placed and locked, the load will start until no greater pressure can be sustained by the concrete and the data is recorded.

2.5 Chemical Composition and Amorphous Silica State of RHA

According to ASTM C 618-92a, the chemical composition of RHA from the sum of SiO_2 + Al_2O_3 + Fe_2O_3 is more than 70%, MgO less than 5%, Na_2O less than 1.5%, and SO_3 less than 5%. RHA can be categorized as pozzolanic material based on the XRF result. Moreover, the investigation of the amorphous silica phase in the RHA is widely done by the X-ray diffraction (XRD) analysis of each produced RHA, focusing on samples at three temperatures (600°C, 700°C, and 800°C) to properly relate the results with the RHA obtained from the lab furnace. A critical review of the literature is established, focusing mainly on the previous parameters to review the composition phases of RHA relative to the RHA conditions in this compressive strength study lab work.

3. Results and Discussion

Discussion of the findings of the compressive strength tests, some on the RHA composition phases and some on the structural state of incinerated RHA. The result obtained will be observed in graphs forms and analyzed.

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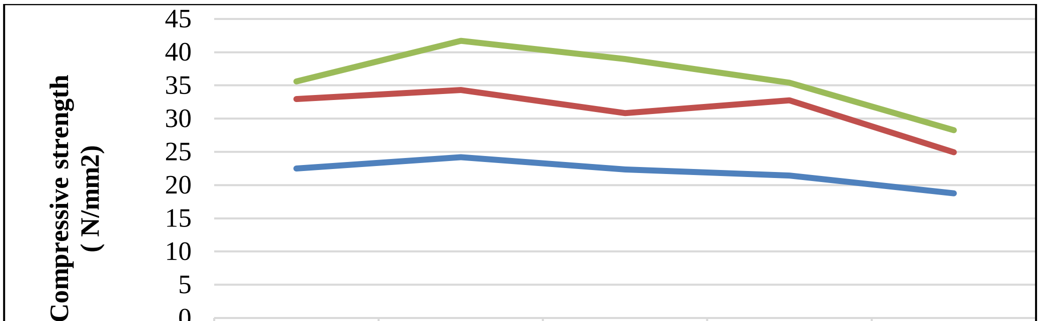
3.1 Compressive Strength Test

The compressive strength values of concrete specimens are presented in Figures 3, 4, and 5. For the partial replacement of RHA incinerated at 600°C, the sample with 5.0% RHA has a compressive strength higher than the control at the early stage, which indicates the RHA in the concrete mixture improved the early strength gain. According to Bie et al. (2015), the increased strength is due to the amorphous silica content and high specific surface area of the RHA.

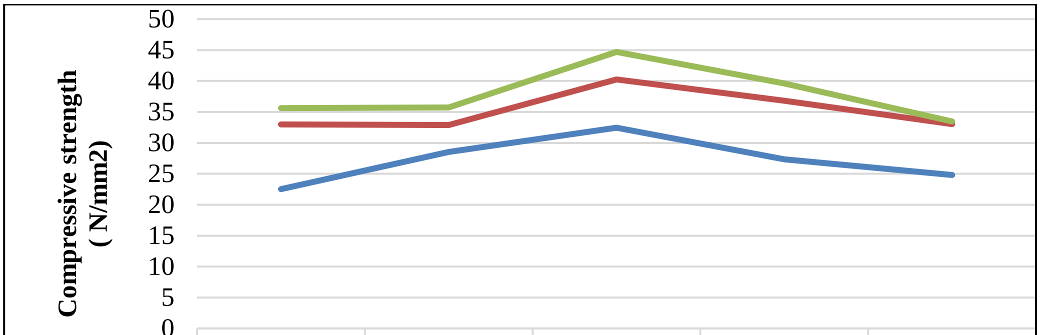
Among the three incineration temperatures of RHA and the four replacement ratios, the 7.5% ratio (7R7.5) exhibited the maximum compressive strength value of 44.7 N/mm2. The higher compressive strength compared to regular concrete is due to the silica inside the RHA beginning to react with the hydration product in the concrete, which is called the pozzolanic reaction. The silica reacts with the calcium hydroxide to form the secondary C-S-H gel, which is the main constituent of the compressive strength. C-S-H gel will fill up the capillary pores in the concrete. The C-S-H gel is refining the pore structure of the concrete; thus, the compressive strength is increased.

Despite having considerable good compressive strength results for RHA incinerated at 800°C it has the lowest results among the burning temperatures of 600°C and 700°C. The compressive strength gradually dropped when RHA calcinated above 800 °C (Xu Weiting, 2013). The lower values of compressive strength are due to the crystalline nature found from XRD graphs at 800°C and above which results in poor pozzolanic activity of RHA and that falls with the agreement to the findings of Xu Weiting (2013).



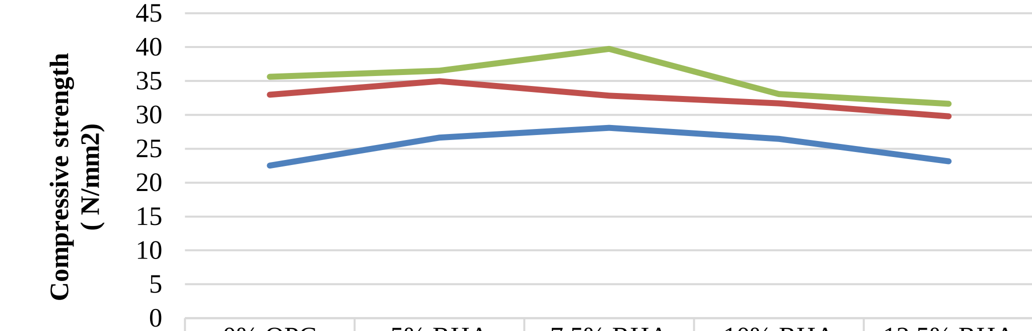
	0% OPC	5% RHA	7.5% RHA	10% RHA	12.5% RHA
7 DAYS	22.52	24.2	22.36	21.43	18.76
14 DAYS	32.96	34.31	30.81	32.77	24.94
28 DAYS	35.62	41.71	38.96	35.42	28.26

Figure 3. Compressive Strength Results of OPC and RHA Concrete Incinerated at 600°C.



	0% OPC	5% RHA	7.5% RHA	10% RHA	12.5% RHA
7 days	22.52	28.52	32.45	27.35	24.79
14 days	32.96	32.88	40.25	36.8	33.02
28 days	35.62	35.71	44.7	39.58	33.46

Figure 4. Compressive Strength Results of OPC and RHA Concrete Incinerated at 700°C.



	0% OPC	5% RHA	7.5% RHA	10% RHA	12.5% RHA
7 days	22.52	26.63	28.09	26.47	23.16
14 days	32.96	34.98	32.83	31.69	29.79
28 days	35.62	36.53	39.74	33.08	31.64

Figure 5. Compressive Strength Results of OPC and RHA Concrete Incinerated at 800°C.

There appears to be a good correlation in curing process between compressive strength and concrete containing RHA. The relationship shown in Figure 5 suggests that the early gain in compressive strength was clearly indicated after 7 days curing of concrete samples. The control concrete compressive strength at 7 curing days was found to be 22.52 N/mm^2.

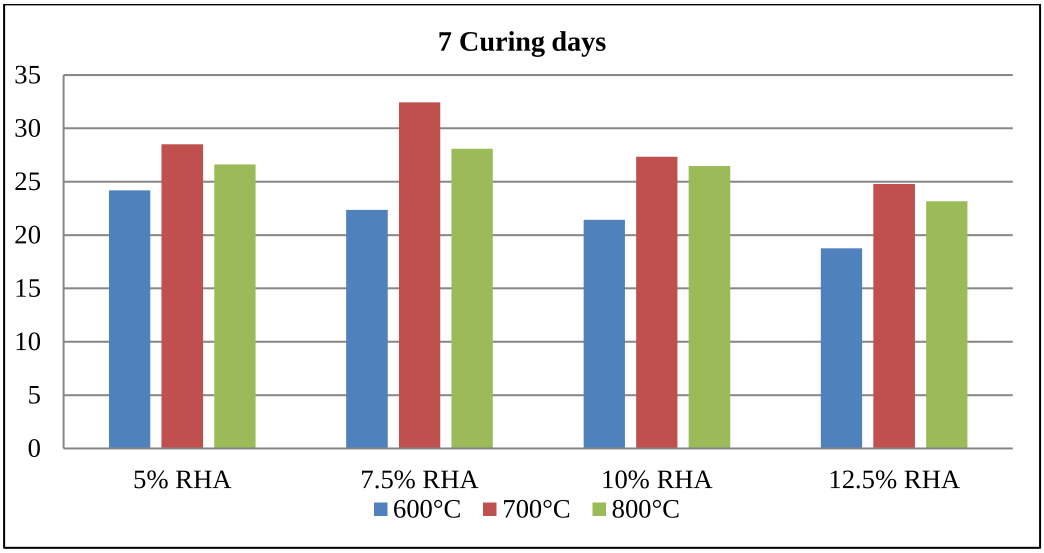


Figure 6. Relationship Between Compressive Strength and 7 Days Curing of RHA Concrete

As shown from the chart, RHA concrete had noticeable higher compressive strength than control concrete sample when cement is replaced by 5%, 7.5% and 10%. Moreover, the maximum strength gained when RHA incinerated at 700°C which support the optimization of RHA replacement percentage with cement is in range of 7.5%.

3.2 The RHA Composition Phases Critical Review

A review of stages of silica produced from rice husk is carried out with assessment of different burning temperatures and suggestions of new research directions with respect to the RHA composition phases.

3.2.1 Chemical Composition Analysis

The chemical oxides composition of rice husk ash (RHA) as obtained by various researchers are shown in Table 2. It can be observed from Table 2 that all the results of the researchers manifested a very high silica content above 70 %. This is a measure of the reactivity of RHA, silica is the compound that has been found to be responsible for the strength in concrete (Nair et al., 2008). This is particularly good for established RHA as having the ability to contribute to the strength development process if used in concrete production. Also, the fact that the sum of SiO_2 + Al_2O_3 + Fe_2O_3 exceeds 70 % for all the RHA specimens demonstrated that the RHA are in the same category with the Class F fly ash (ASTM C618, 2005) with high pozzolanic characteristics. However, the table also reveals a credible fear, that is, the high loss on ignition, which is a measure for the residual carbon content, recorded by all the researchers.

In comparison to research conducted by J. Hadipramana et al (2016), the results confirm the statements of previous literature that the chemical composition of RHA from SiO_2 + Al_2O_3 + Fe_2O_3 is more than 70%, MgO less than 5%, Na_2O less than 1.5% and SO_3 less than 5%, which categorize the RHA as pozzolanic material based on the XRF analysis result and classification of ASTM C 618-92a.

Table 2. Chemical oxide composition of RHA

Temperature	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	LOI	SAF
600ºC	84.85	0.6	0.639	1.132	0.616	0.347	0.391	2.63	8.49	86.02
700ºC	90.58	0.329	0.339	0.976	0.462	0.592	0.494	1.76	5.07	91.21
800ºC	93.3	0.433	0.381	0.834	0.397	0.25	0.197	1.46	3.573	94.17

3.2.2 Structure state of RHA Silica by XRD Analysis

The structure of the silica is often investigated by X-ray diffraction (XRD) and the state is revealed by the shape of the diffractogram obtained. XRD studies revealed that RHA predominantly with amorphous silica exhibited broad peak cantered on 2θ angle of 22° (Amin MN et al., 2019; Habeeb et al., 2009; Bangwar et al., 2017). The study of the researcher Bangwar et al., (2017) on the development of amorphous silica from Rice Husk (RH) waste indicates in their results that the XRDs patterns of RHA samples of 500°C to 800°C have a broad peak at 2θ angle of 19° confirming the material contain an amorphous silica structure and converting to crystalline nature at 900°C.

However, the study found that the extracted ash at the temperature of 800°C for 2 hours duration is the optimum one in terms of amorphous silicon dioxide which is not in agreement with the study of (J. Hadipramana., 2016; Hwang & Chandra., 2016). Thus, to obtain amorphous silica from rice husk, the processing temperature should not exceed 700ºC, as phase transition to the crystalline structure of cristobalite would soon follow, although no specific temperature has been reported for this transformation. Therefore, it is clearly indicating that the production of amorphous silica RHA requires a thorough investigation to standardize the optimum incineration temperature of optimum amorphous silica RHA.

4. Conclusions and Recommendations

The results obtained and the observations made in this research study draw some conclusions. These are:

i. The overall findings in this study suggest that RHA has good potential as a cement partial replacement material. RHA has been found to improve the compressive strength of concrete. Thus, the optimum replacement of cement with RHA in the concrete was 7.5% at the incineration of 700°C.
ii. The compressive strength test results show higher strength than control in the early stages when cement is replaced with RHA.
iii. The incineration temperature of RHA at 700°C had the best results of compressive strength among all incineration temperature samples. In contrast, almost all samples had a relatively stronger result than control samples.
iv. From the critical review of previous studies, the chemical composition of RHA is classified as pozzolana material based on the standard of materials (ASTM C618). Therefore, it exhibits a potentially valuable, cheap alternative to the more expensive natural and synthetic silica for numerous industrial applications.
v. Although general beliefs that the best form of RHA that can be used in concrete or masonry work must be in an amorphous form that is thermally treated between 600ºC to 700ºC, XRD studies illustrate that RHA produced below 700ºC would be in amorphous form and above 800ºC would result in crystalline form.

From this study work, it is glaring that some areas of this are yet to be given attention by researchers and it is recommended for further studies:

i. Long-term investigation including extended ranges of incineration temperatures of rice husk and duration are suggested for future work to study the effect of incineration condition on RHA in dept.

ii. Durability studies such as carbonation, corrosion, and freeze and thaw. Also, the effect of acid-treated incinerated RHA on the performance of concrete, however, has been put forward for suggested future study to obtain a better understanding of this material in concrete.
iii. It is highly suggested that future research carries out an investigation on the compressive strength by combining more types of pozzolans with the RHA to the concrete.

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Declaration of Conflicting Interests

All authors declare that they have no conflicts of interest.

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