Jurnal Kejuruteraan 34(4) 2022: 599-604
https://doi.org/10.17576/jkukm-2022-34(4)-08

Flexural Behavior of Reinforced Concrete Beams by using Rice Husk Ash as Partial Replacement of Fine Aggregates in Cement Concrete

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Received 13 September 2021, Received in revised form 2 October 2021
Accepted 2 November 2021, Available online 30 July 2022

ABSTRACT

Rice Husk has been utilized as a mineral admixture, cement replacement option, and filler in cement concrete as it provides several advantages such as improved strength values and environmental benefits related to the disposal of waste materials and to reduce the carbon dioxide emissions resulting from production of cement worldwide. In this study, flexural behavior of reinforced concrete beams using rice husk ash as a partial replacement of fine aggregates is investigated. For this purpose, four types of concrete mixtures were produced using rice husk ash as a partial replacement of fine aggregates at replacement levels of 0%, 10%, 15% and 20%. The produced reinforced rice husk ash concrete prism specimens were cured in water and tested to determine the ultimate load and ultimate deflection at 28 days of curing. The test results depicted that, the maximum ultimate load carried by reinforced rice husk ash concrete beam is 39.4 KN with 10% rice husk ash at 28 days and minimum ultimate load is 19.02 KN with 20% rice husk ash used as a partial substitute of fine aggregates at 28 days. The minimum ultimate deflection of 0.97mm occurred with 10% rice husk ash as a partial replacement of fine aggregate at 28 days of curing. Hence, this study concludes that 10% RHA can be utilized as a partial replacement of fine aggregates to provide strength in concrete and to reduce the environmental burden of rice husk waste. The results of this study will also provide a way forward to address the recent issues in construction sector, such as depletion of raw materials and increasing cost of construction.

Keywords: Rice husk; concrete; carbon dioxide emissions; flexural strength; fine aggregates; eco-friendly concrete

INTRODUCTION

In Civil Engineering, concrete is the most widely used construction material all over the globe (Jhatial et al. 2018; Raza & Kumar et al. 2020). With the increasing use of concrete, the demand, production, and supply of cement are increasing day by day (Jhatial et al. 2020). It has been reported that the cement production ejects out tons of CO_2 emissions that causes hazards to our living environment (Bheel, Jokhio et al. 2020; Bheel, Memon et al. 2020; Meghwar et al. 2020) which produces concrete and other related materials for construction of infrastructure around the world, after the food production industry. This industry requires a lot of natural resources like aggregates, limestone etc. to produce finished product such as concrete and cement. These natural resources are limited and have to deplete one day, so alternate to these resources are required. On the other hand, this industry produces a large amount of waste material that creates environmental pollution. Thus, recycling the waste as potential raw material and to produce a usable product is the need of present era for sustainable construction. In addition to the environmental hazards caused due to cement production, the generation of agricultural and industrial waste has also increased the issues relating to pollution (Kamaruddin et al. 2021). Various waste materials like fly ash, sugarcane bagasse ash, silica fume, wood waste ash, coal bottom ash, wheat straw ash etc. are being generated in a large quantity. These waste materials have pozzolanic properties that can enhance the strength behavior of concrete as established by various researchers (Ghosal & Moulik 2015; Mangi et al. 2019; Raza, Rai, et al. 2020).

One of such waste materials is Rice Husk. The rice paddy production is around 600 million tons per year which generates approximately 120 million tons of rice husk. One ton of paddy when burnt, gives 0.18 ton of rice husk ash (Krishna et al. 2016). When rice husk is burnt into ash, it fulfills the physical characteristics and chemical composition of mineral admixtures (Memon et al. 2021).

The size of RHA is 25 micron and it can serve as a filler in cement. RHA used in concrete as a partial replacement of cement can also decrease the emission of greenhouse gases to a great extent and reduce the environmental pollution (Rukzon et al. 2009).

The quality and strength in concrete is basically related to its compressive strength. For cheap and economical generation of concrete, the rice husk is used as a partial replacement of cement. It also serves as an admixture in concrete to enhance the properties. Rice Husk Ash (RHA) is highly porous and light weight in nature. It is a waste material that is disposed of by means of labor and machinery which involves various costs (Bheel et al. 2018). The pozzolanic activity of RHA is influenced by content of silica, silica crystallization phase and size and surface area of ash particles (Jhatial et al. 2019). In order to ensure quality of ash, a suitable incinerator/furnace as well as grinding method is required for burning and grinding. It is observed that RHA contains more than 75-80% silica and it shows a lower loss on ignition (Rukzon et al. 2009). Thus, the rice husk ash, if used in concrete production, can reduce numerous costs and environmental hazards (Bheel et al. 2021; Memon et al. 2021; Phulpoto et al. 2020). In addition to this, the concrete also gains strength and durability due to the pozzolanic properties of Rice Husk Ash (Bheel et al. 2018).

The compressive strength of commercial sandcrete blocks was studied in Nigeria. In this study, 150mm x 450mm hollow sandcrete blocks were cast, cured, and crushed for 1, 3, 7, 14, 21 and 28 days at 0, 10, 20, 30, 40 and 50 percent RHA replacement levels. The study suggested that compressive strength of OPC and RHA sandcrete blocks increases with age at curing and decreases as the RHA content increases. The study also suggested that 20% replacement is optimum because the water requirement increases as the rice husk ash content increases (Oyetola & Abdullahi, 2006). The possibility of using unground RHA in structural concrete made with 15% and 25% replacement of cement by mass was studied and the authors concluded that it is technically feasible to use unground RHA in structural concrete up to 15% replacement (Dabai et al. 2009). Other studies based on utilization of RHA as fine sand in concrete suggested that permeability of concrete decreases (Hossain et al. 2015) and the compressive strength increases up to a certain level of replacement and then the strength of concrete also decreases (Obilade, 2014). RHA, when combined with fly ash enhances the properties of concrete. An investigation reported that the compressive and flexural strength increased by 30.15% and 4.57% respectively at combination of 22.5% fly ash and 7.5% RHA (Sathawane et al. 2013).

The research on influence of weight and volume replacement of fine aggregates by RHA on workability, bulk density and compressive strength of concrete was conducted. The replacement levels were 5%, 10%, 15%, 20% and 25%, and the mix ratio was 1:2:4 by weight and volume respectively. The results revealed that the value of bulk density, compaction factor and compressive strength decreases as the percentage replacement of sand with RHA increases (Obilade, 2014). In another study, the durability and compressive strength of concrete using RHA as partial replacement of cement with the use of 1%, 3% and 5% magnesium sulphate solution. The replacement levels were 0% to 20% by weight of cement with 5% increment levels. The concrete specimens were produced and tested at 7, 28 and 60 days and it was observed that the durability of concrete was improved (Sarma et al. 2014). RHA also tends to decrease the strength of conventional concrete when used as replacement of cement at higher replacement levels as claimed by (Abbas et al. 2015) while the strength of high strength concrete made with replacement of cement with RHA at 5%, 10%, 15%, 20%, 25% and 30% by weight of cement also decreases (Guruvu et al. 2016). The usability of RHA in concrete as a mineral admixture was validated by (Nivedita & Rachel 2016). The authors prepared four concrete mixes of M30 grade using silica fume, rice husk ash, copper slag and metakaolin as partial replacement of cement and the concrete blended with RHA exhibited sufficiently adequate bond strength and stress-strain behavior (Nivedita & Rachel, 2016).

Hence, this study sought to check the influence of RHA used as partial substitute of fine aggregates on flexural behavior of reinforced concrete beam at 28 days of curing. The specific objective was to determine the ultimate deflection and ultimate load carried by RHA concrete beam with different percentage of RHA and compare the results with those of normal reinforced concrete beam containing no RHA.

RESEARCH METHODOLOGY

MATERIALS

Locally available concrete ingredients i.e. cement, aggregates and drinkable water along with RHA with fineness of 360 m^2/kg, were utilized for production of concrete mixes and specimens. The raw rice husk and rice husk ash is shown in Figure 1. In this research, crushed aggregates of maximum size 10mm were used and the properties were as detailed in Table 1. Rice husk waste was obtained from nearby having physical properties mentioned in Table. 1. The aggregates were weighed and sieved prior to mixing to ensure the adequate bonding and filling in concrete matrix. The results of sieve analysis are captured in Figure 2 and Figure 3. The fine and coarse aggregates conformed to protocols as set in ASTM C33 (Standard Specification for Concrete Aggregates, 2018). The RHA can be produced by burning the rice husk in a furnace at a temperature ranging from 550 Celsius to 700 Celsius (Memon et al. 2021). The chemical composition of RHA and cement was determined through XRF test and is compared in Table 2. The main reinforcement of #4 bars and the stirrup reinforcement of #2 bars was employed.

FIGURE 1. Rice Husk and Rice Husk Ash (Jhatial et al. 2019; Memon et al. 2021)

TABLE 1. Physical Properties of Fine Aggregates, Coarse Aggregates and Rice Husk Ash

S. No.	Property	Fine Aggregates	Coarse Aggregates	Rice Husk Ash
1.	Bulk Density	19.1 kN/m^3	14.7 kN/m^3	-
2.	Specific Gravity	2.61	2.68	2.10
3.	Water Absorption	1.5%	0.8%	-

TABLE 2. Chemical Composition of Cement and Rice Husk Ash

Chemical Compounds		Content (%) by Weight	
Oxide	Chemical Name	Cement	Rice Husk Ash
SiO_2	Silica	23.43%	86.94%
CaO	Calcium Oxide	64.40%	2.20%
MgO	Magnesia	1.34%	1.31%
Al_2O_3	Alumina	4.84%	0.20%
Fe_2O_3	Iron Oxide	4.08%	0.10%
SO_3	Sulphite	2.79%	0.86%
LOI	Loss on Ignition	5.68%	7.66%

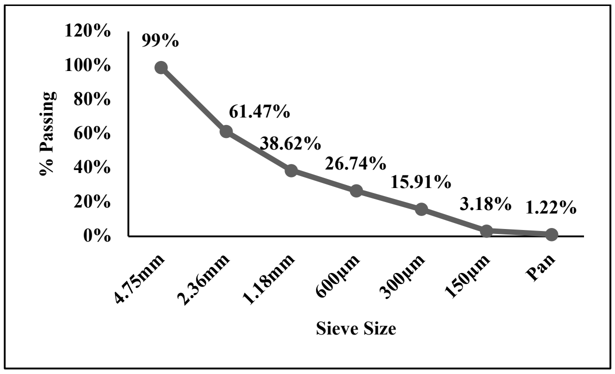

FIGURE 2. Sieve Analysis Results of Fine Aggregates

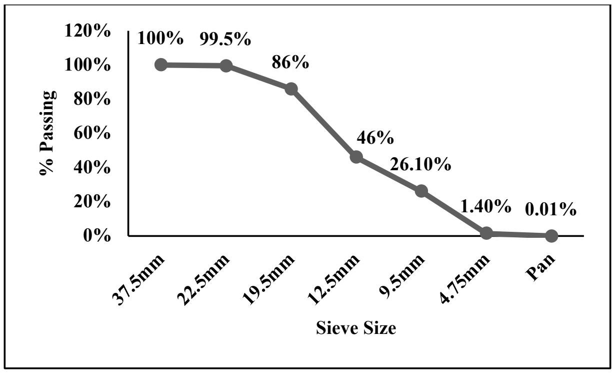

FIGURE 3. Sieve Analysis Results of Coarse Aggregates

MIX PROPORTIONS

The properties and behavior of concrete significantly depend upon different parameters. Hence, before commencement of any experimental work, it is necessary to set the constant and variable parameters. In this study, concrete mix ratio of 1:2:4 @w/c ratio of 0.5 was adopted. The specimens were divided into four batches according to the dosage of RHA used in concrete. Mix proportioning by weight was used and the RHA was incorporated to replace fine aggregates at dosage levels of 0%, 10%, 15% and 20% by weight of the aggregates. In total, twelve beams were casted. The mix proportions were calculated as presented in Table 3.

TABLE 3. Mix Proportions of RHA Concrete

Materials	0% RHA	10% RHA	15% RHA	20% RHA
Cement (kg)	5.25	5.25	5.25	5.25
RHA (kg)	0	1.05	1.57	2.10
Fine Aggregates (kg)	10.5	9.45	8.93	8.4
Coarse Aggregates (kg)	21	21	21	21
Water (kg)	2.62	2.62	2.62	2.62
W/C Ratio	0.5	0.5	0.5	0.5

EXPERIMENTAL METHODOLOGY

The flexural strength is an ability of concrete beam to resist failure in bending. In this study, ultimate load, and ultimate deflection of reinforced RHA concrete beams were evaluated by using RHA as partial replacement of fine aggregates. The specimens used in this experimental study were of dimensions: 500mm length, 100mm height (depth) and 100mm width. Prior to testing, specimens were measured in terms of dimensions. The test for flexural strength of concrete beams under the controlled loading utilizes a beam testing machine which permits the load to be applied normal to the loaded surface of the beam. The beam is centered on the bearing support. The test is conducted by center point loading method (*ASTM C293 / C293M - 16 Standard Test Method for Flexural Strength of Concrete (Using Simple Beam With Center-Point Loading)*, n.d.) or by third point loading method (*ASTM C78 / C78M - 18 Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)*, n.d.) as shown in Figure 4 and Figure 5. The display mounted at top of the apparatus gives the flexural strength values.

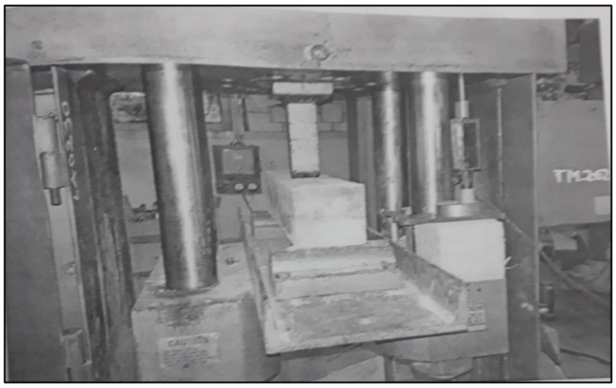

FIGURE 4. Flexural Strength Test Machine

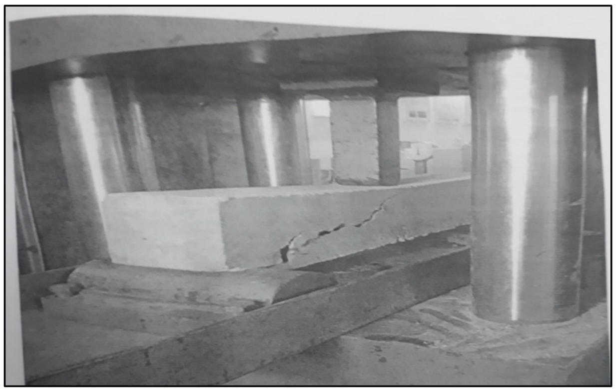

FIGURE 5. Beam subjected to Flexural Strength Test

RESULTS AND DISCUSSION

Flexural behavior of reinforced RHA concrete beams by partial replacement of fine aggregates with different percentages of RHA was investigated and compared with normal reinforced concrete beams. The concrete prisms of 100mm x 100mm x 500mm were prepared and tested to determine the ultimate load and ultimate deflection of reinforced RHA concrete. These specimens were tested at curing age of 28 days. The concrete in prisms was filled in different layers and each layer was compacted by vibrator to ensure adequate bonding and compaction. The specimens were demolded after 24 hours, cured in water at defined temperatures and then tested for their ultimate load and ultimate deflection. It was observed that rate of strength development at various ages is related to percentages of RHA in concrete mix. The results have been detailed in Table 4 and Table 5 and illustrated in Figure 6 and Figure 7 as under. It was observed that the 10% RHA was deemed optimum for adequate flexural sustainability. The results are in line with those of (Abood Habeeb & Bin Mahmud, 2010), (Obilade, 2014) and (Padhi et al. 2018).

TABLE 4. Results of Average Ultimate Load carried by Reinforced RHA Concrete Beams

S. No.	RHA (%)	Average Ultimate Load (KN)	Percentage Variation
1.	0	37.53	-
2.	10	39.41	+5.00%
3.	15	21.86	-41.75%
4.	20	19.02	-49.37%

TABLE 5. Results of Ultimate Deflection of Reinforced RHA Concrete Beams

S. No.	RHA (%)	Average Ultimate Deflection (mm)	Percentage Variation
1.	0	2.04	-
2.	10	0.97	-52.45%
3.	15	1.21	-41.17%
4.	20	1.82	-11.76%

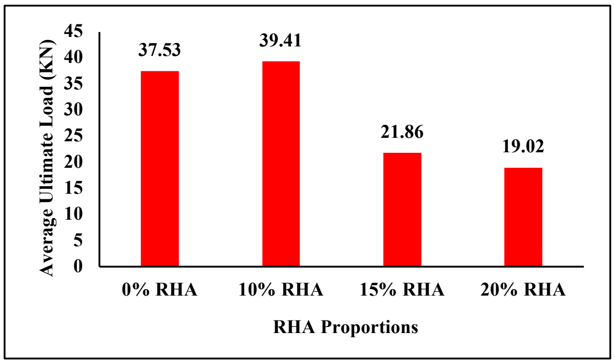

FIGURE 6. Average Ultimate Load carried by Reinforced RHA Concrete Beams

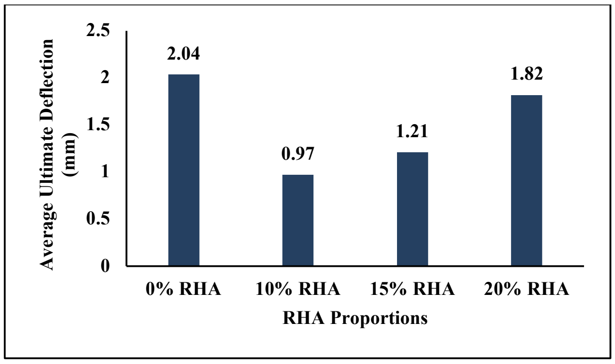

FIGURE 7. Average Ultimate Deflection of Reinforced RHA Concrete Beams

CONCLUSIONS AND RECOMMENDATIONS

To observe the flexural behavior, the ultimate load carried by reinforced concrete beams with 0%, 10%, 15% and 20% RHA as partial replacement of fine aggregates was evaluated. The observations indicate that the ultimate load carried by reinforced concrete beam with 10% RHA as partial replacement of fine aggregates increases by 5% as compared to normal RC beam. For 15% and 20% replacement level, a decrease of 41.75% and 49.37% respectively was observed in ultimate load carried by reinforced RHA beams. In addition, the ultimate deflection of reinforced concrete beam with 10% RHA as partial replacement of fine aggregates decreased by 52.45% as compared to normal RC beam. For 15% and 20% replacement level, a decrease of 41.17% and 11.76% respectively was recorded in ultimate deflection of reinforced RHA beams. The maximum ultimate load carried by reinforced concrete beam with 10% RHA as partial replacement of fine aggregates was 39.4 KN while the minimum ultimate load i.e. 19.02 KN was carried by reinforced concrete beam with 20% RHA as partial replacement of fine aggregates. Since, the ultimate load carried by reinforced RHA concrete beam with 10% RHA as partial replacement of fine aggregates is more than the ultimate load carried by normal reinforced concrete beam, so this type of concrete can be produced where high strength values are required. Similarly, reinforced concrete beams with 10%, 15% and 20% RHA undergo lesser ultimate deflection than normal reinforced concrete beam and hence, to conclude, 10% RHA can be optimum amount for partial replacement of fine aggregates as the reinforced RHA concrete beams with 10% RHA not only carry more ultimate load but also undergo lesser ultimate deflection than normal reinforced concrete beams.

In wake of increasing depletion of raw materials and environmental issues associated with their production, this study provides a way-forward for efficient disposal of RHA. Moreover, it will reduce the use of fine aggregates to make the concrete construction economical and eco-friendly.

ACKNOWLEDGEMENT

The authors would like to thank to Quaid-e-Awam University of Engineering and Technology, Changsha University of Science and Technology, Mehran University of Engineering and Technology, Aligarh Muslim University and Sungkyunkwan University for supporting this research.

DECLARATION OF COMPETING INTEREST

None

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