The Effect of Water-Binder Ratio and RHA on the Mechanical Performance of Sustainable Concrete

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Received: 30 January 2022 | Revised: 16 February 2022 | Accepted: 22 February 2022

***Abstract*-Nowadays, the utilization of industrial energy, as well as construction waste, is of high concern. The current paper describes a study of the mechanical properties of cement concrete mixes utilizing Rice Husk Ash (RHA) as a cement substitute. The use of such industrial and agricultural by-products has been the focus of waste reduction for economic, environmental, and technical reasons. In this research, the compressive and split tensile strength of concrete was studied through a 15% substitution of cement with RHA with 0.40, 0.45, and 0.50 water-binder ratios. It has been found that the addition of RHA significantly improves the mechanical properties of concrete for the used water-binder ratios. The ultimate strength in both compressive and tensile strength was observed at a water-binder ratio of 0.50. It has also been observed that as the water to cement ratio increased, higher gains in concrete's compressive and tensile strength were obtained for all curing periods**

Keywords-rice husk ash; water-binder ratio; slump; compressive strength; tensile ttrength

I. INTRODUCTION

Cement concrete is considered one of the most important building materials and is extensively used in a variety of structures. This material however, also has a significant carbon footprint, as its production accounts for nearly 7% of total greenhouse gas emissions [1]. Efforts have been made to use industrial waste materials in concrete as cement replacements in order to reduce carbon emissions. Utilizing waste in the construction industry helps reducing the disposal problem. During the last few years, many researchers have recognized that the use of pozzolanic materials like Sugarcane Bagasse Ash (SCBA), silica fume, Fly Ash (FA), and RHA, not only improves the characteristics of concrete, but also it provides low-cost construction options [2, 28]. Global production of rice equals nearly 700 million tons per year, and this value is increasing as the consumption of rice is increasing. Table I gives the list of the countries leading the rice growth around the world and the potential production of husk and ash. The use of RHA as a partial cement substitute will provide cheaper materials for low-cost construction. RHA is very rich in silica, however, the silica content depends on the type of rice husk, the burning method, and the combustion period [3]. The utilization of global rice between 2014 and 2015 was estimated to hit 700 million tons [4, 5]. In Pakistan, rice husk is being used as a food additive, and sometimes the by-product of rice husk is used in kilns as fuel. The rice husk used as fuel in kilns and other places generates huge amounts of RHA with no useful application. It is commonly discarded and dumped in open areas taking up a lot of space and causing environmental pollution. This waste has been used as cement replacement to minimize its impact on the environment [6, 7]. RHA can produce pozzolanic activity at temperatures around 400^0C, and, due to the contained water, the amorphous silica present in RHA can also take part in the reaction with $Ca(OH)_2$ to produce C-S-H gel [8, 9, 29]. The addition of RHA in concrete has reached significant importance as it is considered environmentally safe and more durable for infrastructural development [10, 11, 30]. It has been found that using RHA in concrete increases compressive and tensile strength [12, 13, 31], reduces permeability [14] and chemical attacks [15], has minimal effects of Alkali-Silica Reactivity (ASR) [16], reduces the shrinkage due to particle packing, leads to the formation of denser concrete with improved workability [17], reduces heat transfer to the walls of various structures [18], and diminishes the need of superplasticizers [19, 20].

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The aim of this study is to use RHA in concrete and observe its impact on the water-binder ratio, while minimizing its effect on the environment by using it as a cement replacement material.

TABLE I. RHA IN THE TOP 20 COUNTRIES REGARDING RICE PRODUCTION [4-5]

Country	Rice production (tons)	% of total rice production	Produced husk (20% of total) (tons)	Potential ash production (18% of husk) (tons)
China	204,350,000	29.26	40,870,000	7,356,600
India	152,660,000	21.86	30,532,000	5,495,760
Indonesia	69,554,048	9.96	13,910,810	2,503,946
Bangladesh	39,000,000	5.59	7,800,000	1,404,000
Viet-Nam	43,709,000	6.26	8,741,800	1,573,524
Thailand	37,080,000	5.31	7,416,000	1,334,880
Burma	33,200,000	4.75	6,640,000	1,195,200
Philippines	18,500,000	2.65	3,700,000	666,000
Brazil	11,500,000	1.65	2,300,000	414,000
Japan	10,700,400	1.53	2,140,080	385,214
USA	10,606,000	1.52	2,121,200	381,816
Korea	7,509,000	1.08	1,501,800	270,324
Pakistan	5,800,000	0.83	1,160,000	208,800
Egypt	5,700,000	0.82	1,140,000	205,200
Nepal	4,750,000	0.68	950,000	171,000
Cambodia	4,099,016	0.59	819,803	147,565
Nigeria	3,000,000	0.43	600,000	108,000
Sri Lanka	2,710,000	0.39	542,000	97,560
Colombia	2,400,440	0.34	480,088	86,416
Laos	2,350,000	0.34	470,000	84,600
Rest of the world	29,118,000	4.17	5,823,600	1,048,248
Total (world)	698,295,904	100	139,659,181	25,138,653

II. MATERIALS AND METHODS

A. Materials

The materials utilized in this study consist of cement, fine aggregates, coarse aggregates, and potable water. Elephant brand cement was purchased from a local distributor of materials and was used as a binder in all samples. The cement was purchased after checking the date of manufacture, and no cement older than 20 days was used. The fine aggregates used was clean natural hill sand, free from clay and other impurities, having passed through a 4.75mm sieve. The coarse aggregates, with a maximum size of 19mm, were washed and dried before use. RHA was collected from locally available brick kilns in the vicinity of Larkana, Sindh, Pakistan. It is generally the waste material left over after the baking of bricks in kilns. The RHA used in this experimental work was free from other ingredients and passed through a 325-sieve. Drinking water with a pH value of 7.3 was used [21, 22].

B. Methodology

Concrete samples with RHA as supplementary cementitious material with a mix proportion of 1:2:4 were prepared. Three different water to cement (w/c) ratios of 0.40, 0.45, 0.50 were used in the samples. For the RHA-modified concrete mixtures, the cement was substituted with 15% RHA (by weight). Three mixtures of plain concrete and three mixtures of RHA concrete were prepared. For each mixture 30 cubes, and for each age 5 cubes (90 cubes in total), each measuring 150mm×150mm× 150mm were fabricated. Three different curing ages, namely 7, 14, and 28 days were considered. Similarly, for each mixture (30 cylinders) and for each age (5 cylinders), cylinders of 150mm diameter and 300mm height were fabricated in order to check the tensile strength of both concretes with regard to the same curing ages. The concrete samples were fabricated and removed from the molds after one day and were placed in a water tank for the curing periods [23-25].

III. RESULTS AND DISCSUSSION

A. Workability

Slump cone test was carried out for all the prepared concrete mixes to check their workability. The results are presented in Table II. It can be observed that using RHA in concrete causes minimal changes and has a minor effect on workability. However, a reduction in workability was observed due to the higher water absorption due to the presence of RHA in concrete [26, 27].

B. Compression Test

1) Results of Plain and RHA Concrete at 0.40 w/c Ratio

The results of the compressive strength test of the cubes for both plain and the RHA concrete with 15% cement substituted with RHA at 7, 14, and 28 days using 0.40 w/c ratio are given in Table III and Figure 1.

TABLE II. SLUMP CONE TEST RESULTS

Batch	w/c ratio	Mix proportion	Slump of plain cement concrete (mm)	Slump of RHA concrete (mm)
1	0.40	1:2:4	85	81
2	0.45	1:2:4	92	87
3	0.50	1:2:4	96	91

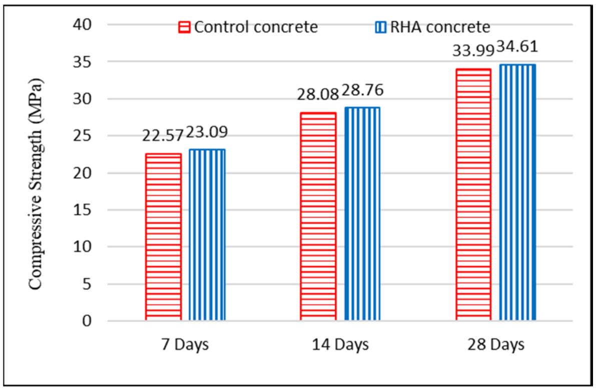

Fig. 1. Comparison of the compression test results of plain and RHA mixed concrete at 0.40 w/c ratio.

TABLE III. COMPRESSION TEST RESULTS, 0.40 W/C RATIO

Curing days	Compression test results of plain concrete (MPa)	Compression test results of RHA concrete (MPa)	Increase in compressive strength of RHA over plain concrete (%)
7	22.57	23.09	2.30
14	28.08	28.76	2.42
28	33.99	34.61	1.82

It can be observed that the compressive strength of the specimens made with RHA concrete is higher than the strength of plain concrete at all ages (7, 14, and 28 days) when using the 0.40 w/c ratio. The maximum compressive strength of the RHA concrete at the age of 14 days is 2.42% higher than the plain cement concrete.

2) Results of Plain and RHA Concrete at 0.45 w/c Ratio

The results of the compressive strength test of the cubes of plain concrete using 15% replacement of cement with RHA at 7, 14, and 28 days when using 0.45 w/c ratio are given in Table IV and in Figure 2.

TABLE IV. COMPRESSION TEST RESULTS, 0.45W/C RATIO

Curing days	Compression test results of plain concrete (MPa)	Compression test results of RHA concrete (MPa)	Increase in compressive strength of RHA over plain concrete (%)
7	20.33	21.55	6.00
14	25.88	27.19	5.06
28	30.62	32.05	4.67

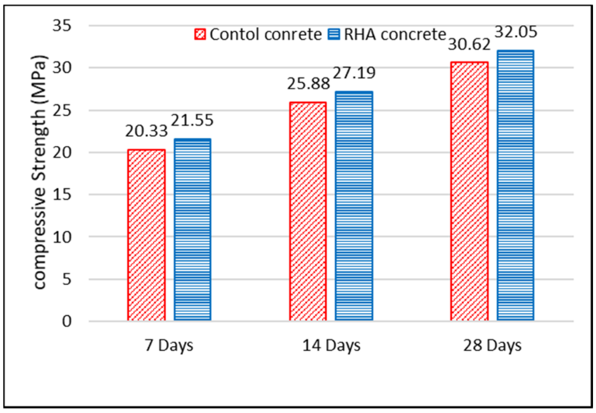

Fig. 2. Comparison of the compression test results of plain and RHA mixed concrete at 0.45 w/c ratio.

It can be seen that the specimens made with RHA have more compressive strength when compared to the control concrete samples at all curing ages. The maximum compression test of RHA concrete at 7 days curing period is 6% more than the control concrete specimens'.

3) Results of Plain and RHA Concrete at 0.50 w/c Ratio

The results of the compression test of the plain concrete and the RHA concrete using 15% replacement of cement with RHA at 7, 14, and 28 days using 0.50 w/c ratio are given in Table V and Figure 3.

TABLE V. COMPRESSION TEST RESULTS, 0.50 W/C RATIO

Curing days	Compression test results of plain concrete (MPa)	Compression test results of RHA concrete (MPa)	Increase in compressive strength of RHA over plain concrete (%)
7 Days	17.41	19.25	10.57
14 Days	21.99	23.96	8.96
28 Days	27.22	30.75	12.97

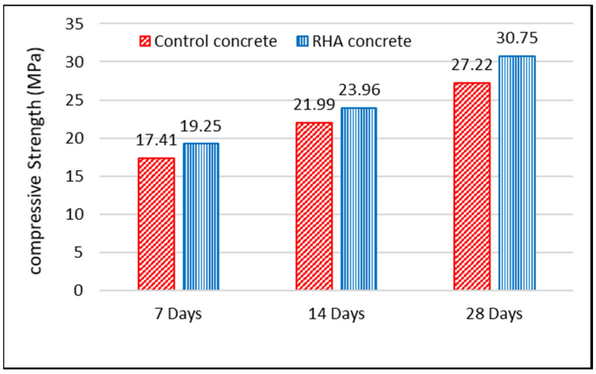

Fig. 3. Comparison of the compression test results of plain and RHA mixed concrete at 0.50 w/c ratio.

The results of the compression test of plain concrete cubes and those with 15% replacement of cement with RHA at 7, 14, and 28 days using 0.50 w/c ratio show a gain in strength for the mixed samples. The maximum compression test result of RHA concrete was achieved at 28 days, and is 12.97% more than the plain cement concrete.

C. Tensile Strength Test

1) Results of Plain and RHA Concrete at 0.40 w/c Ratio

Table VI and Figure 4 show the results of the tensile strength test of the cylinders for control concrete and for RHA concrete using 15% replacement of cement with RHA at 7, 14, and 28 days using 0.40 w/c ratio. It can be observed that RHA concrete has more tensile strength than the control concrete. The maximum tensile strength of RHA mixed concrete is observed at 7 days and is 8.07% more than the plain concrete's.

TABLE VI. TENSILE TEST RESULTS, 0.40 W/C RATIO

Curing days	Tensile strength of plain concrete (MPa)	Tensile strength of RHA concrete (MPa)	Increase in tensile strength of RHA over plain concrete (%)
7	2.23	2.41	8.072
14	2.79	2.99	7.168
28	3.38	3.59	6.213

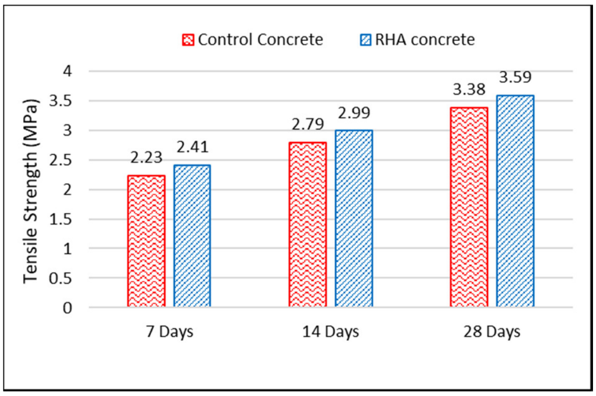

Fig. 4. Comparison of the tensile test results of plain and RHA mixed concrete at 0.40 w/c ratio.

2) Results of Plain and RHA Concrete at 0.45 w/c Ratio

The results of the tensile strength test of the cylinders made from plain concrete using 15% replacement of cement with RHA at 7, 14, and 28 days and 0.45 w/c ratio are given in Table VII and Figure 5. The results at 7, 14, and 28 days show that RHA possesses more strength than the control concrete. Higher tensile strength results were obtained at all curing periods for the RHA concrete specimens. The maximum tensile strength of the RHA concrete at 14 days is 11.88% more than the plain concrete's.

TABLE VII. TENSILE TEST RESULTS, 0.45 W/C RATIO

Curing days	Tensile strength of plain concrete (MPa)	Tensile strength of RHA concrete (MPa)	Increase in tensile strength of RHA over plain concrete (%)
7	2.09	2.33	11.48
14	2.61	2.92	11.88
28	3.03	3.32	9.57

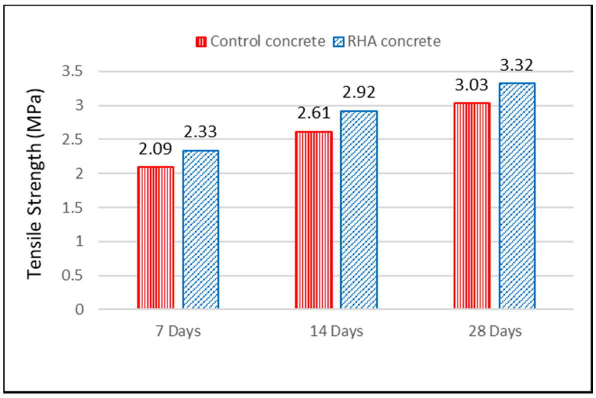

Fig. 5. Comparison of the tensile test results of plain and RHA mixed concrete at 0.45 w/c ratio.

3) Results of Plain and RHA Concrete at 0.50 w/c Ratio

The results of the tensile strength test of the cylinders of plain concrete and those made of RHA concrete using 15% replacement of cement with RHA at 7, 14, and 28 days with 0.50 w/c ratio are given in Table VIII and Figure 6.

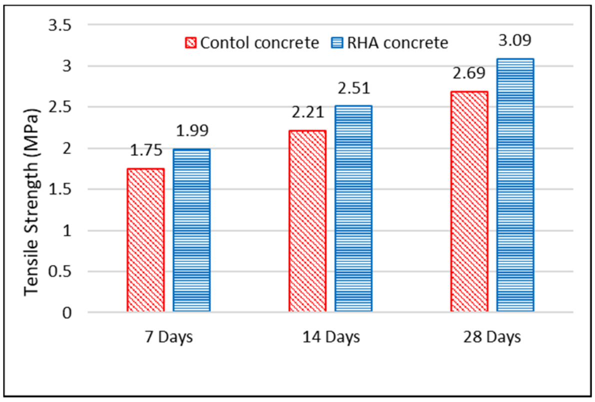

Fig. 6. Comparison of the tensile test results of plain and RHA mixed concrete at 0.50 w/c ratio.

The results show that the tensile strength of RHA concrete is higher than that of control concrete for all curing periods. The maximum tensile strength of RHA concrete was obtained at 28 days curing period, and is 14.87% more than the control concrete specimens'.

TABLE VIII. TENSILE TEST RESULTS, 0.50 W/C RATIO

Curing days	Tensile strength of plain concrete (MPa)	Tensile strength of RHA concrete (MPa)	Increase in tensile strength of RHA over plain concrete (%)
7	1.75	1.99	13.71
14	2.21	2.51	13.57
28	2.69	3.09	14.87

IV. CONCLUSIONS

This study has mainly focused on the inherent mechanical properties, which include compressive and tensile strength, of RHA concrete at different curing periods and various w/c ratios. The results revealed that replacing cement with 15% of RHA improved the mechanical properties for curing periods of 7, 14, and 28 days. From the findings, it could be concluded that:

- The maximum compression test results of concrete specimens made with RHA and with 0.40, 0.45, and 0.50 w/c ratios resulted to 2.42%, 6%, and 12.97% more strength than those obtained using control concrete specimens respectively.
- The maximum increase in compressive strength was achieved when cement was replaced with 15% RHA for 0.50 w/c ratio at 28 days curing period and was 14.87%.
- The increase in the tensile strength of concrete specimens fabricated with RHA concrete with 0.40, 0.45, and 0.50 w/c ratios was 8.07%, 11.88%, and 14.87% respectively.
- The maximum increase in tensile strength when using 15% RHA cement was observed at 0.50 w/c ratio at 28 days, which was 12.97% more than that of plain concrete.
- Cement concrete made with RHA has the property to not only enhance the strength of cement concretebut also to save construction material cost, ultimately making these new structures more economical than the traditional ones.

Furthermore, the use of RHA shown an increase in the strength of concrete at 15% RHA replacement. It has also been observed that as the w/c ratio is increased, higher gains in compressive and tensile strength of concrete were obtained at all curing periods.

ACKNOWLEDGMENT

The authors are grateful to the Quaid-e-Awam University of Engineering, Science and Technology, Campus Larkano for providing the required facilities for this research work.

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