Effect of Water-to-Binder Ratio on Strength of Brick Aggregate Concrete Containing Rice Husk Ash

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Abstract. The present study investigates the effect of the water-to-binder ratio (w/b) on the strength of brick aggregate concrete (BAC) containing rice husk ash (RHA) as a partial replacement of cement. To conduct the study, the properties of the materials were investigated. BAC cylinders (100 × 200 mm) and beams (100 × 100 × 500 mm) were prepared using various percentages of RHA (0, 10, 15, 20, and 25%). The volume ratio of 1:1.5:3 (cement: fine aggregate: coarse aggregate) was used at w/b of 0.45, 0.50, and 0.55. After determining the material properties, the slumps of fresh BAC were measured. The strengths of RHA-based hardened BAC were tested after 28 days. The workability of BAC decreased with increasing RHA content but improved with higher w/b ratios. BAC with up to 15% RHA content achieved higher compressive and tensile strengths than the control BAC (0% RHA) at w/b of 0.50. The maximum compressive and tensile strengths were found at 10% RHA content at w/b of 0.50. However, the flexural strength of BAC with RHA showed inferior performance at all w/b ratios. Thus, BAC with up to 15% RHA content demonstrated enhanced strength at a w/b of 0.50.

Keywords: Brick aggregate concrete, rice husk ash, compressive strength, tensile strength, flexural strength.

1 Introduction

The growth of construction surges the use of cement. The cement factory is one of the main contributors to global warming, generating about 5%–8% of worldwide CO_2. It also emits around 7% of greenhouse gases [1-2]. Researchers are trying to minimize this issue by using waste materials like RHA, fly ash, slag, silica fume, and other pozzolana in making concrete [3-4]. RHA is an agricultural by-product that has been used as a cement replacement in recent decades. This practice has introduced a new concept in construction. Utilization of RHA in construction may solve disposal problems because it has an enormous amount of silica. This silica is not usually biodegradable [5]. It even reduces the cost of construction materials [6]. However, crushed brick is increasingly popular as an economical and lightweight concrete alternative, especially where stone chips are scarce [7].

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On the other hand, the reaction among calcium oxide, silica, and water are the key factors in developing strength of concrete. Hence, the water-to-binder ratio (w/b) is significant in increasing concrete strength [8]. However, after casting, concrete loses water gradually due to leaking and evaporation, becoming hardened. In the absence of water, the hydration process halts [9]. To address this issue, investigators are trying to use RHA in making concrete, as it has a cellular structure that retains water. This water chemically reacts with unhydrated cement grains and silica (contain in RHA). This reaction produces C–S–H gel, which acts as a secondary binder. Thus, strength of concrete increases [10].

According to previous studies, the inclusion of RHA in OPC might increase the amount of water required owing to its high specific surface area and cellular structure [11-12]. This is one of the main difficulties in utilizing RHA in concrete. However, Mehta [13] stated that RHA (up to 3%) does not adversely affect water requirement of concrete. A number of scholars reported that an increase in w/b decreases strength of stone aggregate concrete regardless of RHA replacement [14-15]. However, Noaman et al. [5] found better results for BAC with RHA at w/b of 0.50. Moreover, numerous attempts were made to study the properties of concrete with RHA [5, 7, 10, 14-17]. However, there is a limited number of research on concrete made with broken brick as coarse aggregate and containing RHA [5]. Furthermore, only a few studies are available regarding the effect of w/b on the properties of concrete containing RHA [16-17], but those did not include broken brick as aggregate. To bridge this gap, this study focuses on the effect of w/b on strength of BAC containing RHA.

2 Materials and Methodology

2.1 Test on Materials

For the experiment, locally sourced brick chips of 19 mm downgraded were used as coarse aggregate. The coarse sand was used as fine aggregate. The physical characteristics of these materials were determined through several tests following American Society for Testing and Materials [ASTM] standards, as detailed in Table 1. Both RHA and OPC were sourced locally and used in the experiment. Various tests were using British standard [BS] and ASTM standard (Table 2). The composition of RHA and OPC was assessed through X-ray fluorescence analysis (Table 3). X-ray diffraction (XRD) machine was used to collect the data. This data was then analyzed using MATCH software (V 3.0) to identify the structure and mineral content of RHA. Laboratory-grade water was employed for mixing and curing.

Table 1. Properties of aggregates.

Properties	Fine		Coarse
	Sylhet sand	Local sand	
Fineness modulus (F.M), ASTM C136 [18]	3.11	1.08	7.00
Weight (kg/m^3), ASTM C29 [19]	1510	1270	925
Specific gravity (dry), ASTM C127 [20]	2.67	2.70	2.56
Absorption (%), ASTM C127 [20]	1.03	1.01	16.38
Moisture content (%), ASTM C566 [21]	2.58	2.62	2.03

Table 2. Properties of RHA and OPC.

Materials properties	RHA	OPC
Passed through sieve (mm)	0.075	0.075
Fineness (%)	80	100
Specific gravity (dry), BS 812 [22]	1.78	3.10
Bulk density (kg/m3), BS 812 [22]	390	1440
Normal consistency (%), ASTM C187 [23]	-	28
Color	Grey	Grey black

Table 3. Chemical composition of RHA and OPC.

Oxide composition (%)	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	SO_3	Na_2O	K_2O	MnO	LOI	Reference
RHA	86.29	0.57	0.57	0.62	1.13	0.27	0.12	2.30	0.22	7.35	Present study
Class F pozzolan	(SiO_2 + Al_2O_3 + Fe_2O_3) > 70			-	-	< 5	-	< 3	-	< 12	ASTM C618 [24]
OPC	20.41	5.21	3.47	1.90	64.27	2.71	0.47	0.47	-	0.77	Present study
OPC (ASTM Type-I)	> 20	< 6	< 6	< 6	-	< 3	-	-	-	< 3	ASTM C150 [25]

2.2 Concrete Mixing and Slump Test

All materials (SSD aggregates, RHA, OPC, and water) were kept into the mixture machine. The drum was then rotated for 2 to 3 minutes to ensure a homogeneous mix. The mix proportion was provided by Noaman et al. [5], as detailed in Table 4. The authors [5] focused on determining the optimum water-to-binder ratio for BAC containing RHA. The authors [5] examined specific ratios of 0.45, 0.50, and 0.55 without using chemical admixtures or making water adjustments. Mix ratio of 1:1.5:3 was maintained throughout the study. Prior to casting the test specimens, workability was tested using ASTM C143 [26].

Table 4. Mix proportion of 1 m^3 concrete.

Mix name	RH:OPC	RHA (kg)	OPC (kg)	Water (Kg) w/b ratio 0.45	0.50	0.55	Coarse aggregate	Fine aggregate Sylhet sand	Local sand
BR0 (control)	0:100	0.0	392.7	176.7	196.4	216.0	756.7	309.6	260.4
BR10	10:90	39.2	353.5	176.7	196.4	216.0	756.7	309.6	260.4
BR15	15:85	58.9	333.8	176.7	196.4	216.0	756.7	309.6	260.4
BR20	20:80	78.5	314.2	176.7	196.4	216.0	756.7	309.6	260.4
BR25	25:75	98.2	294.5	176.7	196.4	216.0	756.7	309.6	260.4

2.3 Casting and Testing of Hardened BAC Specimens

Steel cylinder (100 × 200 mm) and prism(100 × 100 × 500 mm) molds were prepared to cast cylindrical BAC specimens and unreinforced BAC beams, respectively. After unloading the fresh concrete from mixture machine, the molds were filled according to ASTM C31 [27]. These molds were kept at room temperature for 24 h. After hardening, they were separated from the molds and marked for identification. They were cured in water for the specified periods. After 28 days, cylindrical specimens were subjected to a compressive strength (f'_c) test following ASTM C39 [28]. In addition, a split tensile strength (f_{sp}) test was done using a UTM at 28 days according to ASTM C496 [29]. The flexural strength (f_r) test was also done on unreinforced concrete beams using a UTM at 28 days following ASTM C293 [30]. For each replacement, the average values from three specimens were recorded.

3 Results and Discussions

3.1 Properties of Materials

The values of properties of coarse and fine aggregates are presented in Table 1. The results of RHA and OPC are given in Table 2. RHA used in this experiment passed through a 0.075 mm sieve with a fineness of 80%. These results are consistent with findings from earlier studies [5, 31-32]. Table 3 confirms that the RHA and OPC were class F pozzolana and ASTM Type-I cement, respectively. Moreover, the XRD result is shown in Fig. 1. It confirms that the silica is in an amorphous form, indicated by the strong broad peak at about 20^0 (2θ). The sharp peak at about 26.63^0 (2θ) indicates the presence of certain amounts of quartz (SiO_2) with a trigonal structure (hexagonal axis). Nearly similar results have been made by Noaman et al. [5].

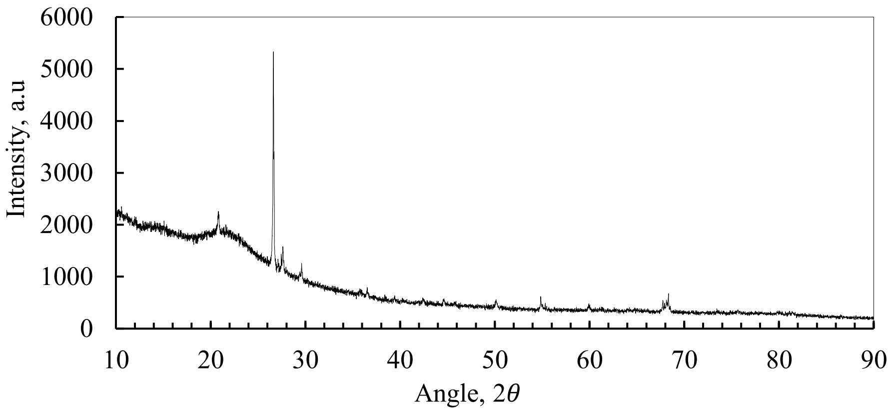

Fig. 1. XRD pattern of RHA.

3.2 Properties of BAC with RHA

The Workability.

The slumps of fresh BAC with and without RHA are presented in Table 5. The slump decreased progressively compared to the control concrete (0% RHA). This decrease is due to the cellular structure of RHA, which naturally absorbs water during the mixing process. The table also indicates that the workability improves with an increase in w/b. However, the best slump value (68.2 mm) for control BAC is observed at w/b of 0.50, while BAC containing RHA indicates better workability at w/b of 0.55. A similar pattern was observed by Noaman et al. [5]. They [5] concluded that the increment of RHA in BAC raises the water requirement.

Table 5. Properties of RHA mixed BAC.

w/b ratio	RHA:OPC	Slump (mm)	28 days strength (MPa)					
			Compressive strength (f'_c)	Improvement of f'_c (%)	Flexural strength (f_r)	Improvement of f_r (%)	Split tensile Strength (f_{sp})	Improvement of f_{sp} (%)
0.45	0:100	30.1	27.10	-	5.63	-	2.29	-
	10:90	23.4	27.76	2.4	5.29	-6.0	2.58	12.7
	15:85	19.1	25.13	-7.3	4.65	-17.4	2.11	-7.9
	20:80	14.0	24.20	-10.7	4.41	-21.7	2.04	-10.9
	25:75	11.4	21.50	-20.7	4.09	-27.4	1.77	-22.7
0.50	0:100	68.2	29.76	-	6.45	-	2.45	-
	10:90	46.5	30.90	3.8	5.85	-9.3	2.81	14.7
	15:85	37.5	30.64	3.0	5.51	-14.6	2.63	7.3
	20:80	21.6	26.75	-10.1	5.21	-19.2	2.12	-13.5

	25:75	16.5	25.06	-15.8	4.69	-27.3	2.18	-11.0
0.55	0:100	150.6	28.52	-	6.2	-	2.39	-
	10:90	101.1	29.31	2.8	5.57	-10.2	2.72	13.8
	15:85	71.5	26.03	-8.7	4.76	-23.2	2.18	-8.8
	20:80	50.8	24.74	-13.3	4.58	-26.1	2.08	-13.0
	25:75	33.0	23.72	-16.8	4.44	-28.4	1.91	-20.1

Note. - Values not available

Strength Properties of BAC Containing RHA. The strengths of BAC with RHA at 28 days are available in Table 5. The control BAC shows better strength (compressive, split tensile, and flexural) at a w/b of 0.50 compared to 0.45 and 0.55. This may be the ideal w/b for BAC. At w/b of 0.45, the control BAC had the lowest slump value (30.1 mm), resulting in numerous voids in the concrete and lower strength than at 0.50. The compressive strength (f'_c) of BAC having 10% RHA increases by about 2.4%, 3.8%, and 2.8% than that of control concrete at w/b of 0.45, 0.50, and 0.55, respectively. The f'_c of BAC with 15% RHA climbed up 3.0% compared to control. However, BAC with 20% and 25% RHA have decreased strength of 10.1% and 15.8% at w/b of 0.50. However, the f'_c of BAC containing 15%, 20%, and 25% RHA experienced a gradual decrease at w/b of 0.45 and 0.55. Although the highest f'_c was achieved with 10% RHA at w/b of 0.50, 15% RHA is the optimal content. The f_{sp} of BAC containing RHA increased with RHA content up to 15%. While the peak f_{sp} of BAC was observed at 10% RHA content, 15% RHA indicates the optimal limit for f_{sp}. The superior performance of BAC containing RHA was observed at higher w/b may be due to the additional water available in the cells of RHA. During hydration, unreacted cement particles chemically react with cell water, forming secondary glue (C–S–H gel). This process reduces permeable voids in BAC, leading to improved concrete strength [5, 31, 33]. BAC containing 10% RHA replacement achieved the highest strength may be due to the ideal replacement level [5]. However, strength declined at 20% and 25% RHA replacements. This may be because excess silica in RHA reduced CaO levels in the OPC, weakening the bond [5]. Moreover, the flexural strength (f_r) was lower than control for all replacement levels and all w/b ratios. This could be influenced by the use of brick aggregate [5]. However, BAC with RHA experienced a better performance at a w/b of 0.50 compared to 0.45 and 0.55 in terms of flexural strength (f_r).

4 Conclusions

The main findings are as follows:

1. The RHA used in this experiment were classified as a Class F pozzolan with amorphous silica.
2. The workability of BAC decreased gradually with increase in RHA replacement but improved with an increase in w/b ratios.

3. BAC containing RHA achieved 3.0%–3.8% higher compressive strength compared to control BAC. It also showed 7.3%–14.7% more split tensile strength. The optimum limit for both strengths was 15% RHA at w/b of 0.50.
4. The flexural strength of BAC with RHA exhibited about 6.0%–28.4% inferior performance compared to the control BAC.

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