Strength Performance of Mortar Prepared with SCBA and RHA as Supplementary Cementitious Materials at Elevated Temperatures

Sajjad Ali Mangi
Department of Civil Engineering, Mehran University of Engineering and Technology, SZAB Campus, Khairpur Mir's, Sindh, Pakistan
sajjad.nec@muetkhp.edu.pk (corresponding author)

Dildar Ali Mangnejo
Department of Civil Engineering, Mehran University of Engineering and Technology, SZAB Campus Khairpur Mir's, Sindh, Pakistan
dildarali@muetkhp.edu.pk

Hemu Karira
Department of Civil Engineering, Mehran University of Engineering and Technology, SZAB Campus Khairpur Mir's, Sindh, Pakistan
hemuKarira@muetkhp.edu.pk

Zahid Hussain
Department of Civil and Architectural Engineering, University of Miami, FL, USA
zxh446@miami.edu

Touqeer Ali Rind
Department of Civil Engineering, Mehran University of Engineering and Technology, SZAB Campus Khairpur Mir's, Sindh, Pakistan
touqeerali@muetkhp.edu.pk

Mohd Haziman Wan Ibrahim
Faculty of Civil Engineering & Built Environment, University Tun Hussein Onn Malaysia, 86400 Parit Raja, Johor, Malaysia
haziman@uthm.edu.my

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ABSTRACT

Rapid urbanization emanates from increased cement production, resulting in a significant increase in greenhouse gas emissions and pressure on natural resources. Considering these repercussions, it is critical to explore alternative methods to mitigate cement production by carefully examining sustainable solutions derived from nature. This study provides an in-depth investigation into the performance attributes related to compressive strength when cement mortar is formulated using Rice Husk Ash (RHA) and Sugarcane Bagasse Ash (SCBA) as supplementary cementitious materials. The experimental approach of this study comprises a comparative measurement of the workability and compressive strength of mortar produced by incorporating RHA and SCBA under standard and elevated temperature conditions, specifically at 400 °C, 600 °C, and 800 °C. The use of RHA and SCBA had a significant impact on mortar workability, showing a trend in which an increasing amount of cement substitution led to a decrease in workability. Furthermore,

the mechanical performance decreased when up to 10% of the cement was replaced with a blend of RHA and SCBA equally divided by 5%. However, a further increase in the RHA-SCBA percentage corresponded to a decrease in the compressive strength. Upon subjecting both the control and RHA-SCBA cement mortar samples to higher temperatures, an anticipated reduction in the strength was observed. However, the samples containing RHA-SCBA demonstrated strength behavior similar to that of the control specimens when exposed to elevated temperature conditions. Based on the findings of this study, both RHA and SCBA are proposed to have the potential to serve as viable replacement materials for the production of cement mortar.

Keywords-RHA; SCBA; cement; flowability; compressive strength; elevated temperature

I. INTRODUCTION

Carbon dioxide (CO_2) emissions from the cement industry contribute 8% of greenhouse gases and their production requires a substantial amount of energy. Cement demand has increased with urbanization, and the rapidly growing population indicates that cement usage will increase in the next 50-100 years. Increasing cement production has increased the cost of raw materials and its negative environmental impact, forcing for finding alternative resources.

Researchers are actively investigating partial replacement of cement with industrial by-products rich in silica that exhibit pozzolanic properties. A supplementary cementitious material must be pozzolanic and silicious or a combination of silicious and aluminous materials that may not have a cementitious identity but react with calcium hydroxide ($CaOH_2$) and water to produce a gel product similar to cement. Various materials such as coal bottom ash, Rice Husk Ash (RHA), silica fume, metakaolin, and millet husk have been found to be promising materials for replacing cement [1-5]. However, the availability of these materials and the specific requirements for use in the construction industry require more materials to be investigated.

Sugarcane Bagasse Ash (SCBA), a sugarcane by-product, is available in large quantities with a significant amount of silica, requiring limited processing to qualify as pozzolanic material [6, 7]. Brazil produces 814.9 million tons of sugarcane, India being second, producing 176.1, and China with 138.3 million tons is the third largest producer. After squeezing, scraped fibrous material (i.e., bagasse) has historically been used for paper production [8]. It is also used to produce steam and energy in the boilers of sugar mills. Bagasse is burned at 500-550 °C in a co-generation boiler to maintain its calorific value. The after-ignition products are called bagasse ash, and the burning process discussed above does not result in significant emissions of greenhouse gases and particularly CO_2. Preliminary research has shown that sugarcane can be considered a pozzolanic material because of the presence of silica.

The production of 1 kg of rice would leave 0.28 kg of rice husks producing huge amounts of waste annually. These husks are used as fuel in various industries and after complete combustion, they leave 20-25% of RHA by weight and require large landfill areas for disposal [9]. The presence of silica and CaO in RHA makes it an effective supplementary cementitious material [10, 11].

Previous investigations have demonstrated the efficacy of RHA and SCBA as individual cementitious substitutes. However, our work suggests that a combination of these materials could yield enhanced outcomes, as exploring their performance at elevated temperatures remains a crucial area for further research. Thus, this study aims to partially replace cement with SCBA and RHA and to analyze their binding properties in mortar under normal and high temperature conditions, advancing our understanding in this scientific domain.

II. MATERIALS AND METHODS

A. Materials

In total, 72 cubes with dimensions of 50 mm × 50 mm × 50 mm were prepared by replacing Ordinary Portland Cement (OPC) with 0%, 5%, 10%, and 15% RHA and SCBA. The RHA:SCBA ratio was maintained at 1:1 in all samples. Table I summarizes the details of the prepared samples. The rise husk was obtained from a local paddy and incinerated at 700 °C for two hours. The ash was ground for 2 h to obtain RHA, which was passed through a 45-micrometer sieve. Figure 1 shows the rice husk, the grinding of the incinerated RHA and the final RHA used for the production of mortar (from left to right). Figure 2 shows the preparation of SCBA from raw sugarcane. As listed in Table I, 36 specimens were tested at normal temperatures and 36 at elevated temperatures. CM-0 indicates the control specimens with 100% OPC, whereas BM-10, BM-20, and BM-30 were prepared with 10%, 20%, and 30% OPC replacement with 1:1 RHA and SCBA.

TABLE I. DETAILS OF THE SPECIMENS

Sample	Material content (%)			# of samples at room temperature			# of samples (28days) at elevated temperatures		
	OPC	SCBA	RHA	3 days	7 days	28 days	400 °C	600 °C	800 °C
CM-0	100	0	0	3	3	3	3	3	3
BM-10	90	5	5	3	3	3	3	3	3
BM-20	80	10	10	3	3	3	3	3	3
BM-30	70	15	15	3	3	3	3	3	3
Total				36			36		

Fig. 1. Preparation of RHA from rice husk.

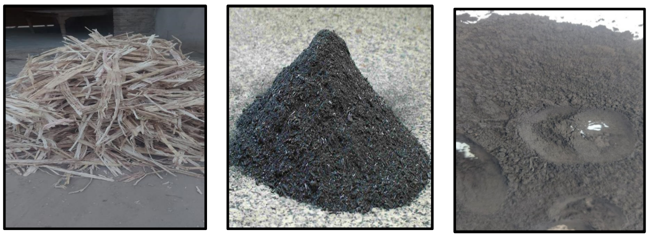

Fig. 2. SCBA was obtained from a sugar mill.

Mortar was prepared for a design compressive strength of 20 MPa. In accordance with (BS EN 206, 2013), the mixture proportions for mortar per cubic meter were 1494 kg of sand, 498 kg of ordinary Portland cement, and 249 kg of water: with a water-to-cementitious material (w/cm) ratio of 0.5.

Table II lists the chemical composition of OPC determined by X-ray fluorescence according to BS EN 196-2:2013 [13]. The chemical composition of RHA was consistent with previous research [2]. The chemical composition of SCBA is consistent with that reported in the literature [14].

TABLE II. CHEMICAL COMPOSITION OF CEMENT, RHA, AND SCBA

Chemical composition (% wt)	Percentage composition		
	Cement	RHA	SCBA
SiO_2	20.78	88.0	76.34
Al_2O_3	5.11	0.97	8.35
Fe_2O_3	3.17	0.45	3.80
CaO	60.22	1.71	2.15
SO_3	2.86	0.79	0.48
Sp. Gravity	3.13	2.08	1.97

B. Test and Observation Methods

1) Characterization of Fresh Mortar

The properties of the fresh mortar were measured and compared among the four mortar mixes at various replacement levels. A flowability test was conducted to measure the workability of the mixes. The C1437 ASTM, 2007 standard was adopted [15]. Figure 3 shows the flow table test of RHA-SCBA mortar conducted in the laboratory.

Fig. 3. Flow table test of RHA-CBA mortar.

2) Mechanical Characterization

The compressive strengths of the mortar cubes of 50 × 50 × 50 mm^3 were measured according to the ASTM C109/C109M-21, 2008 standard [16]. The samples were cured under normal curing conditions with fresh water until the day of testing. The samples were tested to determine the optimal percentage of RHA and SCBA as replacement materials for OPC and their behavior under elevated temperature conditions. Figure 4 shows the cement mortar specimens during casting and before testing.

Fig. 4. Mortar specimens during casting and before testing.

III. RESULTS AND DISCUSSION

A. Fresh Concrete Properties

As shown in Figure 5, replacing part of the OPC with 10% RHA and SCBA (BM10) reduced flowability by 4% compared to the control. The flowability was further reduced for the BM20 and BM30 samples, showing 34% and 53% reductions in flowability, respectively. The reduction in flowability can be attributed to the porous structure and large surface area of RHA, which absorbs more water than the control mix [2]. RHA contains macro-and mesopores within its particles, and with increasing fineness, its surface area increases [15]. Fine RHA subsequently absorbs significant amounts of water on its surface and stores water in its pores, reducing workability [17]. In addition, the shape of SCBA particles is irregular, angular, and highly porous, which absorbs more water and reduces workability [8]. These results are consistent with those of other studies in which lower flowability and setting time were observed [2, 18].

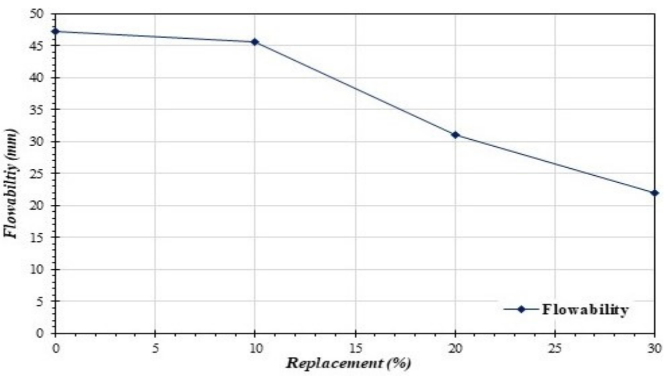

Fig. 5. Flowability of the RHA-CBA mortar.

B. Mechanical Characteristics of Hardened Mortar

1) Compressive Strength at Normal Temperature

Figure 6 presents the compressive strength values of the tested specimens at normal and elevated temperatures. As shown in Figure 6, replacing part of the OPC with RHA-SCBA resulted in a slight decrease in the compressive strength of the mortar. Three days after mixing, the compressive strength of RHA-SBCA with a 10% replacement level was 8% lower than that of the control mix. The strength of the mix with 20% and 30% RHA-SCBA was reduced by 26% and 44%, respectively. The reduction in strength may be attributed to the lower amount of water available for hydration (i.e., RHA-SCBA absorbs more water because of its texture) and the late pozzolanic activity. However, after seven days, the strength of the RHA-CBA mixes was still lower than that of the control mixes, and the reduction in strength was 6%, 25%, and 43% lower than that of the control mixes. A similar trend was observed after 28 days of curing, where strength reductions were 7%, 26% and 47% for the BM10, BM20 and BM30 samples, respectively. The reduction in the compressive strength of the BM samples could be attributed to the delayed pozzolanic reaction. Various studies have verified that the pozzolanic reaction starts after 20-28 days, as confirmed in the current study [2, 8]. The RHA-CBA specimens may show better results at longer ages (i.e., 56 – 90 days, not part of this study). Furthermore, the strength gain decreased with increasing replacement percentage, which is consistent with the literature [2, 8]. According to the results, replacing 10% of the OPC with RHA-CBA was the optimum replacement percentage.

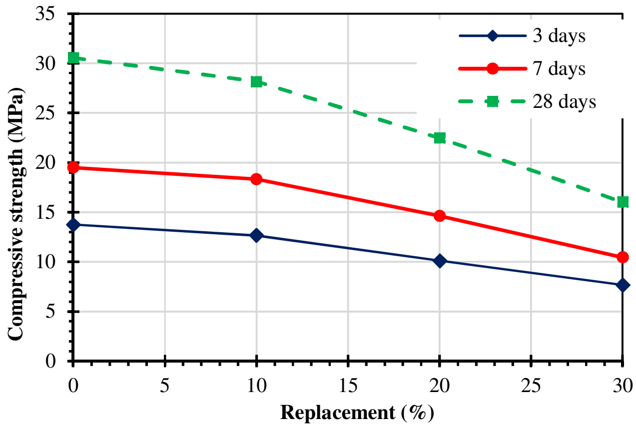

Fig. 6. Compressive strength of RHA-SCBA mortar.

2) Compressive Strength After Exposed to Elevated Temperatures

The samples were subjected to elevated temperatures and the compressive strength was estimated. Increasing the temperature resulted in lower compressive strength as shown in Figure 7. For example, the control sample showed a compressive strength of 30.56 MPa at room temperature, which was reduced by 7% (28.4 MPa) at 400 °C. Similarly, the BM samples exhibited a reduction in their compressive strength when subjected to elevated temperatures. However, the reduction in compressive strength observed with the addition of RHA-SCBA was lower at elevated temperatures compared to the room temperature samples. For instance, the BM10 sample at 400 °C for 28 days of curing exhibited a 4% reduction in compressive strength, but at normal temperature showed an 8% reduction. Possibly the higher temperatures increase the reaction rate. A higher percentage replacement with RHA-SCBA resulted in a lower compressive strength. When the temperature increased to 600 °C, the strength of 10% RHA-SCBA was equal to 12.4 MPa, whereas that of the control mix was equal to 13.1 MPa. The strength of the RHA-CBA sample was only 5% lower than that of the control mixture. However, the overall strength of both mixes decreased because of the elevated temperatures. When the temperature increased further to 800 °C, the strength of 10-RHA-SCBA was 8.8 MPa, and that of the control mix was equal to 9.8 MPa. Although the strength of the RHA-SCBA specimen was close to that of the control mix, the overall strength decreased significantly as the temperature increased. A similar trend was observed in the 20% and 30% replacement levels, where the strength of all specimens decreased.

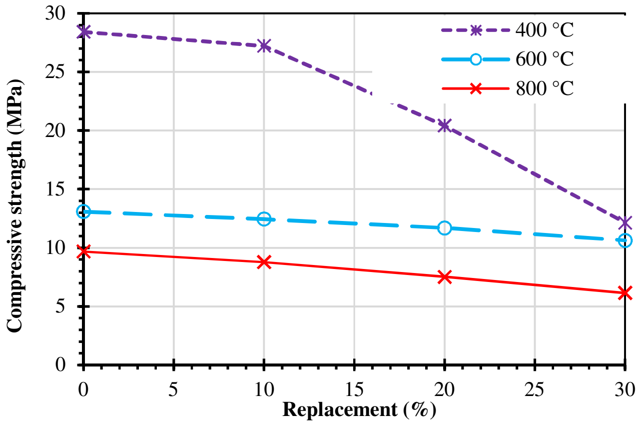

Fig. 7. Compressive strength of RHA-SCBA mortar specimens at elevated temperatures.

IV. CONCLUSIONS

This study considered a novel approach for replacing up to 30% of ordinary Portland Cement (OPC) with Rice Husk Ash (RHA) and Sugarcane Bagasse Ash (SCBA). This study focuses on the compressive strength performance of cement mortars with and without RHA-SCBA at normal and elevated temperatures. To produce RHA, rice husks were obtained from a local paddy and incinerated at 700 °C for two hours. The SCBA was collected from a sugar mill. 72 specimens with 10%, 20%, and 30% of 1:1 RHA:SCBA ratio were tested under compressive loads at 37 °C, 400 °C, 600 °C, and 800 °C. Interesting results were obtained from this study. First, the flowability of the cement mix decreased with increasing RHA-SCBA content. The samples with RHA-SCBA after 3, 7, and 28 days exhibited slightly reduced compressive strengths compared to the control. Furthermore, all samples exhibited a reduction in compressive strength with increasing temperature. The lowest compressive strength was noticed at 800 °C. Replacing up to 30% of OPC with RHA-SCBA resulted in a reduction in the compressive strength, which is analogous to the RHA-SCBA content. However, at elevated temperatures, the RHA-SCBA samples exhibited less compressive reduction with increasing RHA-SCBA content. The reduction in compressive strength can be attributed to the water-absorbing capability of RHA and SCBA owing to their porous structure and delayed pozzolanic action. This problem could be solved by adding more water or water-reducing admixtures to the starting mixture. Further research by studying the samples at 56, 90, and 180 °C could help reveal the pozzolanic activity of the RHA-SCBA cement mixtures over time.

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