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Evaluation the Effect of Replacing Cement with Rice Husk Ash on Self-Compacting Concrete Properties

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ABSTRACT

Rice husk ash (RHA) produced under certain conditions from rice husk as an agricultural surplus material can be used in concrete as a pozzolanic material. Pozzolanic materials improve the durability properties of concrete mainly, but their effects on fresh properties and strength can be different depending on the constituent materials and type of concrete. In this paper, RHA produced from the rice farms of Khouzestan province, Iran has been evaluated for the optimal level of replacement in self-compacting concrete (SCC). To this end, the fresh properties and compressive strength of SCC have been investigated. The used RHA contains 87% silica, mainly in the amorphous state, and has an average specific surface area of 399 m2/kg. The results obtained in this research show that increasing RHA up to 15 % can improve the fresh properties by up to 10%, but it reduces the compressive strength by about 10%. So the 10-15% replacement of cerement with RHA is recommended.

Keywords:

Pozzolanic materials, Compressive strength, Slump flow, J-ring, V-funnel.

1. Introduction

Pozzolans are silica or silica and aluminum materials that alone have no adhesion value (they are not cement) or their adhesion value is low (they are weak cement), but in the form of very small particles, they react with calcium hydroxide (Ca(OH)2) at normal temperature in the wet environment and produce calcium silicate hydrate (C-S-H) compounds. C-S-H gel is the primary reaction product of cement hydration and constitutes over 60% of hydrated Portland cement (in volume). This component is responsible for the strength and durability development of concrete [1, 2]. There are two types of pozzolans; natural pozzolans and artificial or industrial pozzolans [3, 4]. Natural pozzolans exist in raw or calcined types and mainly include non-crystalline volcanic ash. Artificial pozzolans are fly ash, silica fume (microsilica), Blast furnace slag and rice husk ash (RHA) [5,6]. Rice is one of the first food materials used by human beings; it has been used in many parts of the world since thousands of years ago. It is included in food and even in many places of the world it is considered the main meal. Rice husk is an agricultural surplus obtained from the outer covering of rice grains during the milling process. Rice husk constitutes about 20% of the weight of rice. World production of paddy rice was 760 million tons in the year. Historically, the rice husk as a fuel was turned into ash by burning in village ovens at a temperature ranging from 300°C to 450°C [7]. When the husk was subjected to uncontrolled burning below 500°C, the ignition was not complete and a significant amount of non-burning carbon was found in the ash. If the amount of carbon is high, the color of the ash will be dark. In this condition, if the carbon content is more than 30%, it is expected to hurt the pozzolanic activity of RHA. Ash is produced by the controlled burning of rice husk between 500°C and 700°C burning temperature for one hour to convert the amount of silica in the ash to the amorphous state [8,9] The reaction of amorphous silica is directly proportional to the specific surface area of the ash is [10,11]. The produced ash is pulverized or ground to the required level and mixed with cement to produce blended cement [12]. The use of RHA in ordinary vibrated concrete has been studied by researchers [13]. Self-compacting concrete (SCC) is a kind of flowable concrete whose properties are mainly different from ordinary vibrated concrete. The mix design [14-15], constituent materials, and properties of self-compacting concrete (SCC) are fundamentally different from ordinary vibrated concrete. The most important differences include the low water-cement ratio, high fine aggregate, low coarse aggregate [16-17], the use of viscosity modifying agents, and the use of superplasticizers [18-19]. These differences have caused high fluidity and relatively high strength of SCC. For this reason, it is necessary to perform such research in special concretes such as SCC.

In this paper, we aim to evaluate the effect of replacing Portland cement with RHA on the fresh and strength properties of SCC. Tests are performed in two steps based on standard test methods. In the first step, fresh concrete tests include slump flow, J-ring, and V-funnel. In this way, the properties of SCC will be determined. In the second step, the compressive strength of SCC containing RHA has been tested and the optimal range for RHA is suggested.

2. Materials and mix designs

According to *EFNARC* [20], determining the mix proportions of the SCC should be done in a way that provides the desired properties including filling ability, passing ability, and stability. The required degree of these characteristics is a function of the density of the rebars, the shape and size of the mold, and the construction methods; therefore, in the pre-mix design step, the desired characteristics should be checked [20]. Based on this information, in this paper, the following mixt designs were used, which have different RHA-to-cement ratios. Grading of the aggregates are

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shown in Figure 1. The raw Rice husk, produced RHA, and ground RHA are shown in figure 2.a, 2.b, and 2.c respectively.

Table 1. SCC mix design.

mix	C (kg)	W (kg)	w/p(%)	S (kg)	G1(kg)	G2(kg)	CSP (kg)	RHA (kg)	SP (kg)	VMA (kg)	RHA/C (%)	S/A (%)
SR0	436	181.5	0.30	706	603	259	175	0	5.75	0.18	0	45
SR5	414.2	181.5	0.30	706	603	259	175	20	5.75	0.18	5	45
SR10	392.4	181.5	0.30	706	603	259	175	41	5.75	0.18	10	45
SR15	370.6	181.5	0.30	706	603	259	175	55	5.75	0.18	15	45
SR20	348.8	181.5	0.31	706	603	259	175	69	5.75	0.18	20	45
SR25	327	181.5	0.31	706	603	259	175	81	5.75	0.18	25	45

C: cement; W: water; p=C+CSP+RHA; S: sand; G1: fine gravel; G2: coarse gravel; CSP: clay stone powder; SP: super plasticizer; A=S+G1+G2, RHA: ;rice husk ash; VMA: viscosity modifying agent

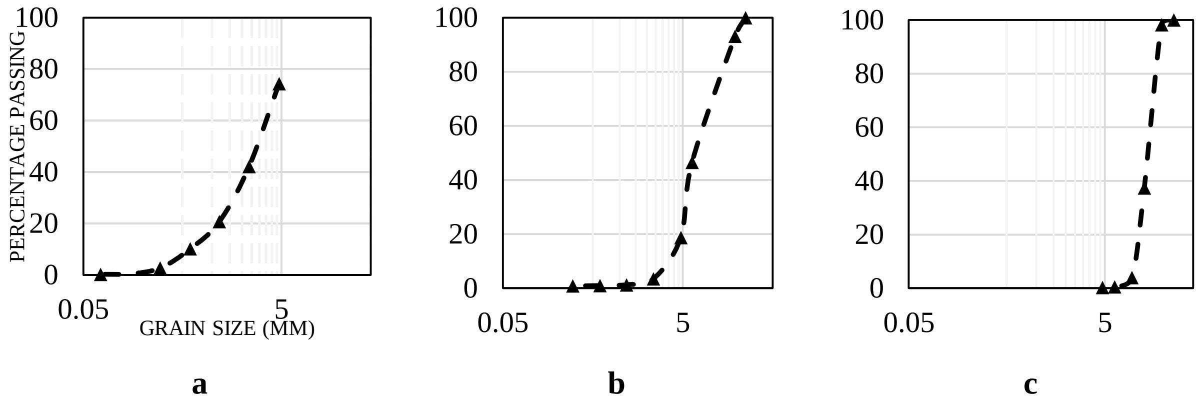

Figure 1. Grading curves of aggregates, a. sand, b. G1 and c. G2.

Polycarboxylates-based super plasticizer PC5000 (HR) with a specific weight of 1100 kg/m3 and a concentration of 20% following the European standard EN-934-2 is used [21]. Type 5 Portland cement is used in making concrete. Granulated river sand passed through a 4.75 mm sieve with a modulus of softness of 3.8 and a specific gravity of 2.55 was used as fine aggregate. Locally available broken carbonate aggregate passed through a 19 mm sieve, remaining on a 4.75 mm sieve and with a specific gravity of 2.7 was used as fine aggregate. Coarse aggregate is in the range of 25 mm to 4.75 mm. The remaining ash of the milled shell burned in a furnace with a temperature of 700 °C for more than 5 hours was used in concrete production. The materials are ground in the Los Angeles machine containing twenty steel balls that were 50 mm to 30 mm diameter before they are used as cement supplementary materials so that their specific surface area exceeds 280 m2/kg according to Blain's method.

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a. Rice husk ash (RHA) b. Burnt rice husk ash (RHA) b. Ground RHA used in making concrete

Figure 2. Raw, burnt, and ground rice husk.

To measure the appropriateness of the produced ash, two XRD and XRF analyses were performed to identify the phases and the percentage of elements that make up the material, respectively. According to the elemental analysis, the highest amount of silica is at the highest temperature, but this silica has mostly a crystalline phase. Considering that crystalline silica does not have pozzolanic properties and must be amorphous, the high temperature of the furnace is not necessarily useful. According to the XRF analysis, the best pozzolanic state with the most amorphous silica occurs at a temperature of about 700 degrees Celsius. Based on XRF test results and using Design Expert software, Figure 3 shows the effect of ash burning temperature and time on silica content.

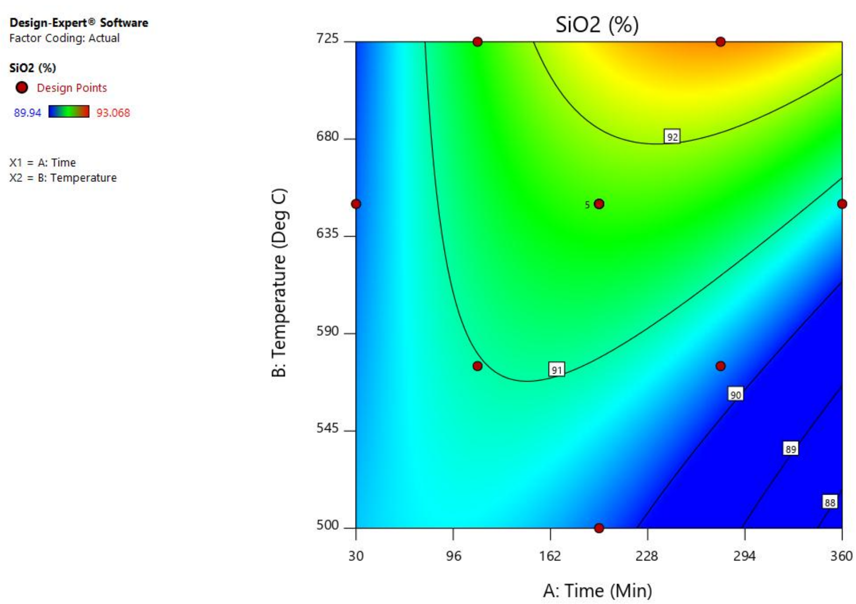

Figure 3. Effects of time and temperature on SiO_2, time range 30 to 360 minutes and temperature range 500 to 725 Celsius degrees by response surface method (output of Design-Expert software).

3. Tests and Results

There are several test methods for each of the performance characteristics (filling ability, passing ability, and stability). Based on the results of some of these tests, various guidelines and standards have classified SCC in terms of performance. Slump flow test is one of the most widely used tests of SCC and is a method for measuring the filling ability of this type of concrete. Based on the slump flow test, The European guide of self-compacting concrete [20] divided the SCC into three levels SF1, SF2, and SF3 for different applications. SF1 is suitable for the use of concrete in structures with little steel or without steel. SF2 is suitable for concreting in concrete structures, usually reinforced, whose mold is not complex and its rebar is not dense. SF3 is suitable for concreting reinforced concrete structures with a complex mold or dense rebar. These levels require 550 to 650 mm, 660 to 750 mm, and 760 to 850 mm of slump flow, respectively. Figure 4.a shows the slump flow test and Figure 4.b shows the J ring test. Based on visual inspection, both tests show adequate flow and passing ability properties of concrete. The results of fresh concrete tests are given in Table 2. The results show that the increase of RHA increases the diameter of the slump flow test. Also, of course, in different dosages, the slump flow is such that the properties of self-compaction are preserved. The J-ring test simulates the passing ability of concrete through obstacles, especially dense reinforcements in the formwork. This test can be used to obtain the passing ability of SCC. To perform this test, it is necessary to wet the base plate and the inner part of the slump cone and place the center of the J-ring in its center. After pouring 6 liters of concrete into the slump cone and smoothing the surface of the concrete on top of it, the cone is pulled up vertically at a constant speed and we let the concrete flow freely. The difference in the height of the concrete inside and outside the J-ring is measured and averaged at four points. The lower the difference in height between the inner and outer parts of the armatures, it means the ability to pass is greater. The allowed difference for SCC is considered to be 10 mm. The results of the J-ring test show that the passing property is improved by adding ash. The V funnel test is used to measure the filling ability of self-compacting concrete. The measurement criterion in this test is time. Based on the results, it can be seen that with the increase of ash, the V funnel time has decreased; this means that concrete has better self-compacting properties. According to the *EFNARC* standard, all tests have the minimum acceptable level and therefore all doses are acceptable.

Table 2. The results of fresh and hardened concrete tests for the desired designs.

mix	Slump flow (mm)	J-ring (mm)	V-funnel (sec)	Strength (MPa)			
				3-day	7-day	14-day	28-day
SR0	652	2.5	10	25	27.7	35.9	42.5
SR5	655	2.5	9	24.5	27.5	34.3	42.9
SR10	680	2	7	23.9	27.1	33.4	38.8
SR15	672	1.5	7	22.3	26.9	32.1	37.1
SR20	671	1.5	8	20.2	25.5	32.1	37.8
SR25	663	2	9	22.4	25.2	32.5	36.2

In Table 2, RHA is measured as a percentage relative to the amount of cement.

a. Slump flow test b. J-ring test

Figure 4. Slump flow and J-ring tests.

The compressive strength of SCC cube samples containing RHA at the ages of 3, 7, 14, and 28 days of moisture treatment are given in Table 2. In some applications, 1-day compressive strength tests have also been reported. It was not possible to test the strength of 1 day in the made concrete and the molds were opened after 48 hours. Perhaps the reason can be considered the use of type 5 cement. The concrete mixture was designed as SR0 as the control sample and SR5-SR25 for RHA mixed concrete.

a **b**

Figure 5. a. Cube samples of concrete; b. hydraulic jack.

Based on the results shown in Table 2, the compressive strength of concretes was determined according to BS 1881: PART 116 standard [22] using three 150 mm cubic samples (figure 5)[23]. Sampling was done without applying any energy and the samples were demolded after 48 hours and were cured according to the standard until the time of the test. During the opening of the mold, the samples were kept moist. figure 6 shows the fresh and strength tests results. figure 6.a shows

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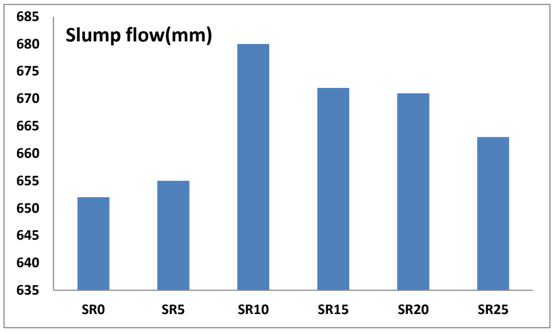
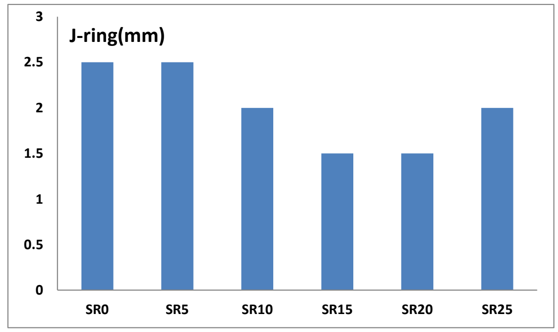
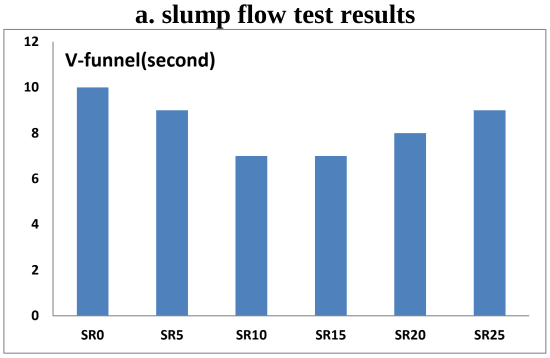
the increase in the slump flow up to 10% replacement and then decrese the fluidity of the mixes. Figure 6.b shows the overall decrease in j-ring results with RHA increasing. Figure 6.c shows the similar results of v-funnel test. Based on these results, it can be said that with the increase in the amount of RHA, the fluidity becomes better and the passing ability becomes weaker. The stability is not much affected by the amount of RHA.



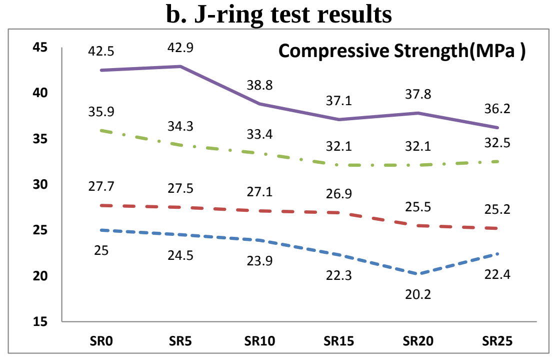
a. slump flow test results



b. J-ring test results



c. V-funnel test results



d. strength in different ages

Figure 6. SCC fresh and strength tests results in different RHA contents.

The compressive strength of concrete cubes has been determined after 3, 7, 14, and 28 days of curing in water ponds. Based on the results in Figure 6.d, it can be seen that the strength has decreased at all ages with the increase in the amount of RHA. This amount of reduction in younger ages is more than in older ages. In this way, it can be said that up to the age of 28 days, increasing the amount of RHA in SCC has caused a decrease in strength. In this way, RHA as a pozzolanic material containing amorphous silica can be used as a substitute for cement; but it should be noted that the use of this material in SCC may cause a decrease in strength.

4. Conclusion

According to the results of this research, in the temperature range of 500°C to 725°C, according to the volume of rice husk, it is possible to produce ash with good quality. Based on the results of this research, the fresh properties do not show a worrying change due to the use of RHA. Therefore, the use of RHE in the range of particle size used in this research will not have any limitations in terms of fresh properties. The optimal replacement percentage of RHA for making SCC concrete is 10% to 15%, which caused a slight decrease in compressive strength and improved efficiency compared to the control sample.

5. Appreciation

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