Coventry University and
The University of Wisconsin Milwaukee Centre for By-products Utilization,
Second International Conference on Sustainable Construction Materials and Technologies
June 28 - June 30, 2010, Università Politecnica delle Marche, Ancona, Italy.
Special Technical Proceedings ed. P Claisse, E Ganjian, F Canpolat and T Naik
ISBN 978-1-4507-1488-4 http://www.claisse.info/Proceedings.htm

Mechanical Properties and Durability of Concretes Containing Rice Husk Ash as Supplementary Cementing Material

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ABSTRACT

Replacement of cement with pozzolan in the production of concrete not only improves the mechanical properties and durability of concrete but also decreases the amount of consumed cement in construction projects as well. Rice Husk Ash (RHA) is a by-product of the agricultural industry which contains high amount of silicon dioxide (SiO_2). For many decades, the concretes incorporating RHA as an artificial pozzolan have been noticed for its qualities and properties. In this paper, in order to supply typical RHA, a special furnace was designed and constructed in Amirkabir University of Technology. XRD and XRF techniques were used to determine the amorphous silica content of the burnt rice husk. Consequently, temperature of 650 degrees centigrade and 60 minutes burning time was found to be the best combination. Then, various experiments were carried out to determine properties of concretes incorporating optimum RHA.

INTRODUCTION

Sustainable development of the cement and concrete industry requires the utilization of industrial and agricultural waste components. At present, for a variety of reasons, the concrete construction industry is not sustainable. Firstly, it consumes huge quantities of virgin materials which can remain for next generations. Secondly, the principal binder in concrete is Portland cement, the production of which is a major contributor to greenhouse gas emissions that are implicated in global warming and climate change. Thirdly, many concrete structures suffer from lack of durability which may waste the natural resources. So, finding a solution to substitute a practical recycled product for part of the cement seems to be desirable for sustainable development. [Mehta 1994]

Recycling of waste components contributes to energy savings in cement production, to conservation of natural resources, and in protection of the environment. Furthermore, the use of certain components with potentially pozzolanic reactivity can significantly improve the properties of concrete [8-14]. One of the most suitable sources of pozzolanic material among agricultural waste components is rice husk, as it is available in large quantities and contains a relatively large amount of silica. When rice husk is burnt, about 20% by weight of the husk is recovered as ash in which more than 75% by weight is silica. Unlike natural pozzolan, the ash is an annually renewable source of silica. It is worth mentioning that the use of RHA in concrete may lead to the improved workability, the reduced heat evolution, the reduced permeability, and the increased strength at longer ages. [Zhang and Malhotra 1996]

In Iran, rice production has increased during these years, becoming the most important crop. Rice husks are residue produced in significant quantities. While in some regions, they are utilized as a fuel in the rice paddy milling process, in our country they are treated as waste, causing pollution of environment and disposal problems. Due to increasing environmental concern, and the need to preserve energy and resources, efforts have been made to burn the husks under controlled conditions and to utilize the resultant ash as a building material. In addition, rice husks are able to be an ideal fuel for electricity generation [Ramezanianpour et al. 1997].

The use of Rice Husk Ash (RHA) in concrete was patented in the year 1924 [Pitt 1972]. Up to 1978, all the researches were concentrated to utilize ash derived from uncontrolled combustion. Mehta published several papers dealing with rice husk ash utilization during this period. He established that burning rice husk under controlled temperature– time conditions produces ash containing silica in amorphous form [Agarwal 2006].

Depending on production method, the utilization of rice husk ash as a pozzolanic material in cement and concrete provides several advantages, such as improved strength and durability properties. Rodrı´guez de Sensale [Rodrıguez de Sensale 2006] reported that mortars and concrete containing RHA have compressive strength values inferior or superior to that of OPC concrete. In addition, in most of the cases [Chindaprasirt et al. 2007], mortars and concrete containing RHA improve durability of concrete at various ages.

Generally, there are two types of RHA in concrete. The type of RHA which is suitable for pozzolanic activity is amorphous rather than crystalline. Therefore, substantial research has been carried out on producing RHA containing high amount of amorphous silica. The results have shown that RHA quality depends on temperature and burning time.

In fact, for an incinerator temperature up to 700 °C the silica is in amorphous form and silica crystals grew with time of incineration. The combustion environment also affects specific surface area, so that time, temperature and environment also must be considered in the processing of rice husks to produce ash of maximum reactivity [Nehdi et al. 2003].

EXPERIMENTAL PROGRAM

Materials

The following materials were used in the preparation of the concrete specimens. Local natural sand according to ASTM Standard with maximum aggregate size of 4.75 mm; Crushed granite according to ASTM Standard with maximum aggregate size of 19 mm; Tehran potable water, Type I Portland cement and optimized and homogeneous rice husk ash produced by following procedure.

From literature review it can be concluded that burning rice husks at temperature below 700°C produces rice husk ashes with high pozzolanic activity [Ramezanianpour et al. 2000]. Firstly, ashes used for investigating properties of RHA concrete were produced by burning rice husks from North of Iran in the furnace. The highest temperature in the furnace was maintained below 750°C. This temperature was recorded in the fire zone where the rice husk was burnt. The measured temperatures were 550, 600, 650, 700 and 750°C. Furthermore, time of burning was another variable parameter that was investigated at 30, 60 and 90 minutes. In addition, an ash sample was processed at temperature of 1100°C for a few minutes. The temperatures can be varied by regulating the blowing air. Therefore ashes with various contents of un-burnt carbon were obtained.

To identify and quantify the major and minor elements present in the samples of obtained rice husk ash, X-Ray Fluorescence (XRF) analysis was carried out. The results are given in Table 1. The chemical compositions of the RHA indicate that the material is mainly composed of SiO_2. The table implies that the ashes produced in the specially designed furnace at low temperature or during 30 minutes are not appropriate due to high loss on ignition. So, they are not appropriate for RHA concretes. Based on the results in Table 1, Figure 1 can be drawn out. Figure 1-(a) can be used to obtain silicon dioxide content from temperature and time duration of burning ashes and figure 1-(b) shows variation of LOI value vs. temperature and time. Fig. 2 shows a photo of rice husk, high carbon RHA, optimum RHA and RHA with crystalline silica.

Afterward, to determine the crystalline compounds present in the various rice husk ash specimens, X-ray Diffraction (XRD) test was carried out. Fig 3 shows XRD patterns of the ashes. The ash patterns were denoted as RHA-Temp.-Min. respectively. The figure shows that silica in the rice husk initially exists in the amorphous form, but will not remain porous and amorphous, when combusted for a prolonged period at a temperature above 650°C, or during less than a few minutes at 1100°C, under oxidizing conditions. It means that the reactivity of rice husk ash is generally decreased by the increase of burning temperature and the heating duration. Burning rice husks at temperature below 650°C produces amorphous crystals of rice husk ashes. Combination of 650°C temperature and 60 minutes burning time seems to present the optimized solution resulting in non-crystallize RHA and lowest burning time. Table 2 shows the characteristics of RHA (RHA-650-60) and the cement.

Table 1. Results of XRF on Rice Husk Ash Samples and Cement

temperature and time duration		SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3	MgO	Na_2O	K_2O	P_2O_5	TiO_2	LOI
550	60min	75.22	0.05	0.14	0.57	0.37	0.36	0.07	1.47	0.51	0.01	21.01
	90min	80.76	0.03	0.09	0.66	0.23	0.43	0.05	1.72	0.79	0.01	14.95
600	60min	80.55	0.02	0.24	0.59	0.34	0.39	0.06	1.65	0.44	0.02	15.33
	90min	85.60	0.06	0.15	0.87	0.22	0.41	0.06	1.53	0.48	0.02	9.81
650	30min	76.21	0.08	0.22	0.86	0.21	0.31	0.08	1.69	0.52	0.01	19.53
	60min	89.61	0.04	0.22	0.91	0.15	0.42	0.07	1.58	0.41	0.02	5.91
	90min	90.21	0.06	0.27	0.85	0.25	0.49	0.08	1.51	0.56	0.02	5.48
700	30min	81.35	0.09	0.15	0.77	0.18	0.33	0.08	1.72	0.53	0.02	14.53
	60min	89.93	0.06	0.11	0.88	0.14	0.39	0.09	1.48	0.55	0.02	6.01
	90min	92.19	0.09	0.10	0.71	0.09	0.41	0.05	1.64	0.41	0.01	4.14
750	30min	84.22	0.09	0.18	0.54	0.17	0.38	0.06	1.35	0.61	0.02	12.09
	60min	93.11	0.08	0.27	0.67	0.11	0.44	0.06	1.69	0.63	0.02	2.67
1100	a few min	95.31	0.04	0.11	0.78	0.11	0.41	0.09	1.61	0.45	0.01	0.84
type I Cement		21.50	3.68	2.76	61.5	2.5	4.8	0.12	0.95	0.23	0.04	1.35

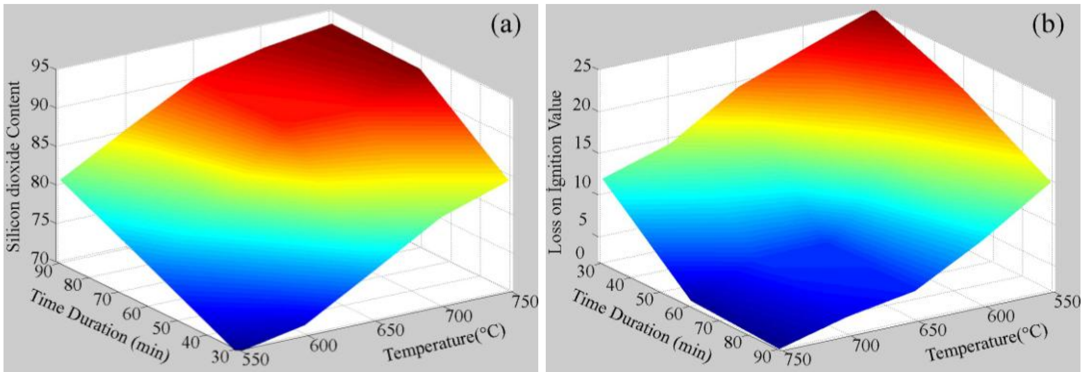


Fig. 1 Estimated Variation of (a) SiO_2 and (b) LOI vs. Temperature and TIME duration

Table 2. Physical and Chemical Characteristics of RHA (RHA-650-60) and Cement.

	Physical Tests		Chemical Analyses, %								Bogue Comp. %			
	Specific Gravity	Blaine, (cm^2/gram)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	LOI	C_3S	C_2S	C_3A	C_4AF
RHA	2.15	3600	89.61	0.04	0.22	0.91	0.42	0.07	1.58	5.91	—	—	—	—
cement	3.21	3200	21.50	3.68	2.76	61.50	4.80	0.12	0.95	1.35	51.1	23.1	5.1	8.4

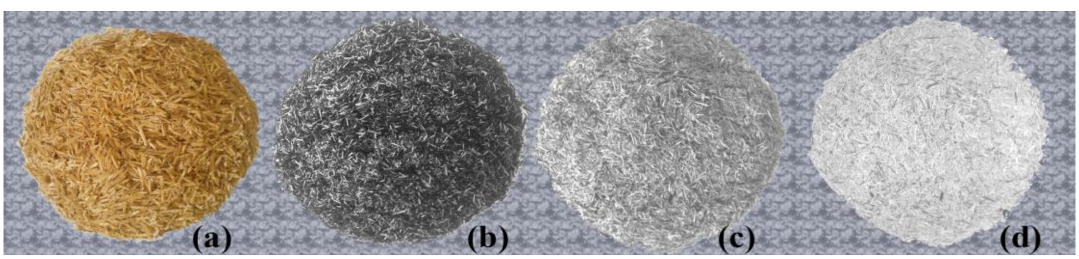


Fig. 2 (a) Rice Husk, (b) High Carbon RHA, (c) Optimum RHA, (d) RHA with Crystalline Silica.

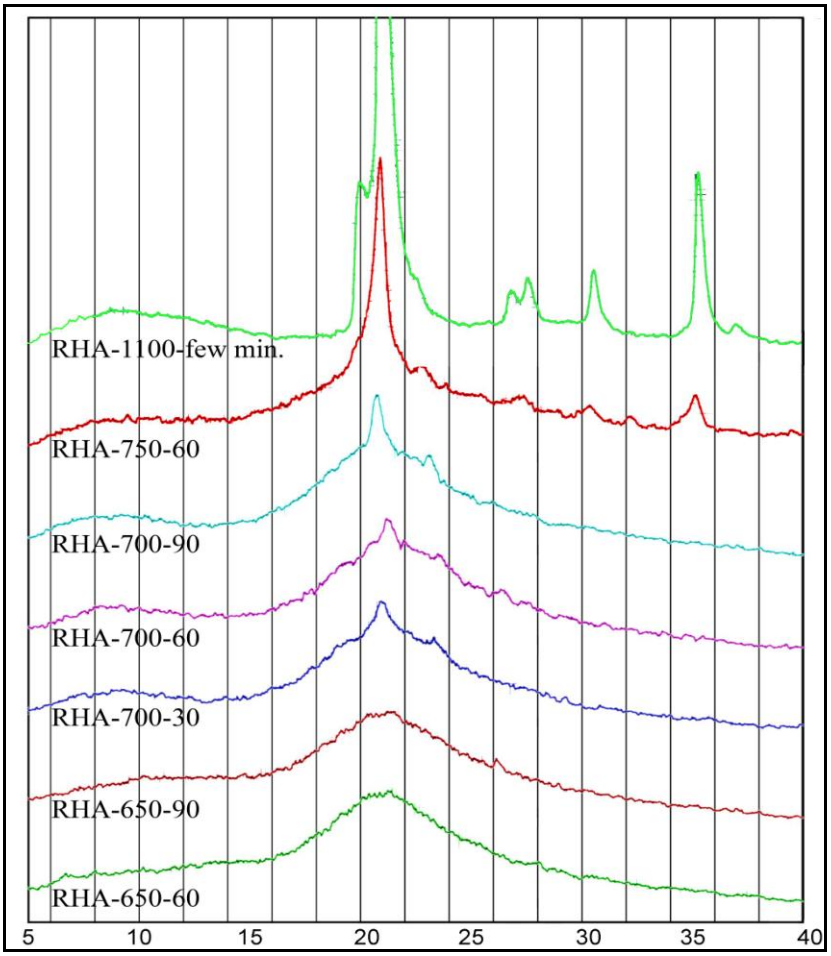


Fig 3. Results of XRD on Rice Husk Ash Samples and Cement

TEST METHODS

A total of 4 concrete mixtures were made; one corresponding to a control concrete (CTL) and three others with 7%, 10% and 15% RHA replaced with cement by weight. Table 3 lists the mix proportions of concrete. Slumps were kept constant at 70 ± 10 mm. Superplasticizer with polycarboxylate base was used at very low percentages according to the results obtained for the slumps. Concrete test specimens were compacted by external vibration and kept protected after casting to avoid water evaporation. After 24 hour they were demolded and cured in lime-saturated water at 23 ± 2°C to prevent possible leaching of $Ca\ (OH)_2$ from these specimens.

Concrete cubes of 100×100×100 mm dimension were cast for compressive strength and water penetration tests. The results obtained are reported as an average of two tests. Samples of rapid chloride permeability tests (RCPT), according to ASTM C 1202, were prepared by cutting and discarding 25mm slices from the top and bottom of 100×200 mm cylinders, and the remaining section cut into three 50mm thick slices. The water permeability test was conducted using a high-pressure permeability cell. The specimens used were cubes of 150×150×150 mm dimension. 100X200 mm cylinders were prepared for measuring the electrical resistivity. All specimens were moist cured until the time of testing.

Table 3. Mix Proportions of Concrete

	RHA (kg/m^3)	cement (kg/m^3)	Aggregate (kg/m^3)		SP/cement (%)	water/ cement
			Fine	coarse		
CTL	0	350	960.3	795.7	0	0.5
7%RHA	24.5	325.5	960.3	795.7	0.15	0.5
10%RHA	35	315	960.3	795.7	0.25	0.5
15%RHA	52.5	297.5	960.3	795.7	0.40	0.5

TEST RESULTS

Results of the compressive strength of concretes are given in Figure 5. In general, the RHA concrete had higher compressive strength at various ages and up to 90 days when compared with the control concrete. The results show that it was possible to obtain a compressive strength of as high as 47.5 MPa after 28 days. In addition, strengths up to 58.4 MPa were obtained at 90 days.

Results of the rapid determination of chloride permeability of concrete test (Figure 6) show that using RHA drastically enhances resistance to chloride penetration compared to control concrete which on average, around 4~5 times higher for the 15% RHA. At 28 days, the control concrete showed the highest value of 4263 coulombs while the charge passed through the 15%RHA concrete was only 1146 coulombs.

With a continuous moist-curing of up to 90 days, the charge passed through all concretes; was reduced. The charge for the 15%RHA concrete was reduced to 698 coulombs, which was well below that of the control concrete (3354 coulombs). According to ASTM C 1202, when the charge passed through concrete is below 1000 coulombs, it is categorized as a very high resistance concrete to chloride ion penetration.

The chloride permeability of the concrete specimens incorporating 15%RHA was “very low”, while that of the concrete specimens with 0%, 7%, 10% RHA were “moderate”, “low” and “low”, respectively, as per ASTM C 1202 criteria.

In addition to RCPT, investigations of water permeability were carried out. In this test, water was forced into the concrete samples from one side for three days and under constant pressure of 0.5 MPa. Then, the samples were split in a plane parallel to the direction of water penetration, and the greatest depth of water penetration into the concrete sample was measured. The depth of water penetration of concrete incorporating RHA specimens is shown in Figure 7. As expected, depth of water penetration of concrete specimens decreased significantly with an increase in RHA content and curing period.

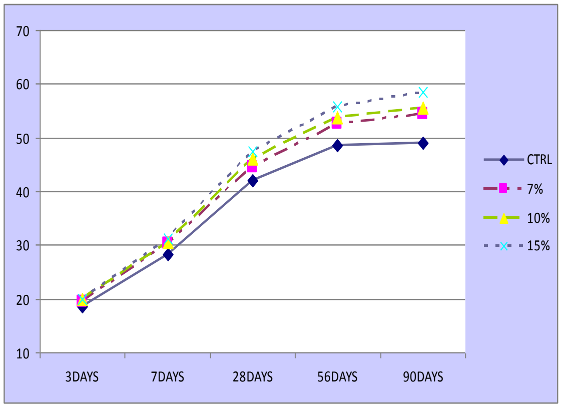
The electrical resistivity meter was used to measure the surface resistivity at the ages of 28, 56 and 90 days. Saturated cylinders (100 x 200 mm) were used at each test age. The electrical resistivity test for concretes was carried out by the four-point Wenner array probe technique. The probe array spacing used was 40 mm. The resistivity measurements were taken at four quaternary longitudinal locations of the specimen. Results of the electrical resistivity test are given in Figure 8. Electrical resistivity enhanced by increasing in RHA replacement by cement weight.

The masses of the specimens were measured after 0, 3, 6, 24 and 72 h of absorption. The sorptivity coefficient (S) according to BS EN-480-5:1997 [12] was obtained using the following expression:

$$\frac{Q}{A} = c + S\sqrt{t}$$

where Q is the amount of water adsorbed; A is the cross section of specimen that was in contact with water; t is the time (second); c is the constant coefficient; and S is the sorptivity coefficient of the specimen (cm/h$^{1/2}$).

Table 4 shows the influence of RHA on the sorptivity of concrete specimens at the age of 28, 56 and 90 days. Results show that the increasing in RHA replacement by cement weight, decreases the sorptivity.



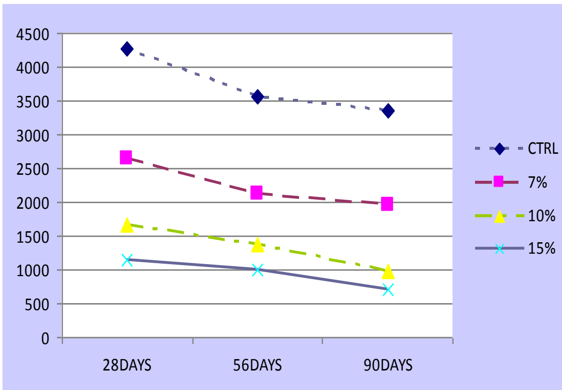
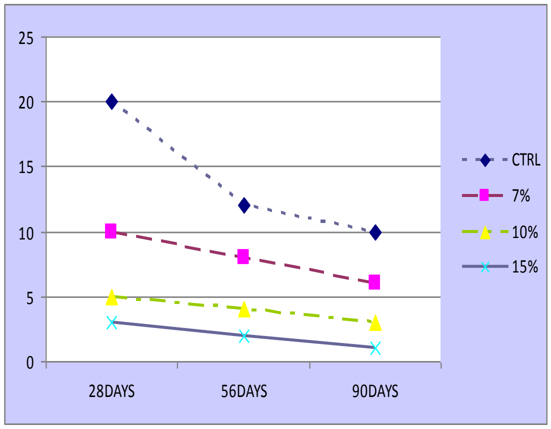


Fig. 5. Compressive Strength (MPa) at Various Ages for Control (CTL) & RHA Mixtures Fig. 6. Resistance to Chloride Ion Penetration (Coulomb) at Various Ages for (CTL) & RHA Mixtures



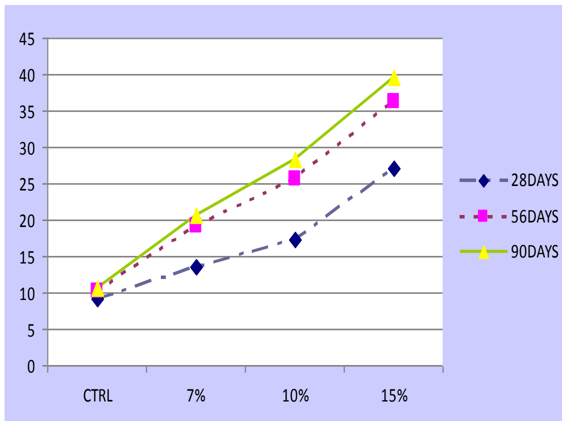


Fig. 7. Depth of Water Penetration (mm) at Various Ages for Control (CTL) & RHA Mixtures Fig. 8. Electrical Resistivity (kohm) at Various Ages for Control (CTL) & RHA Mixtures

Table 4.The effect of RHA on the sorptivity coefficient (cm/h$^{0.5}$) at various ages.

	28 days	56 days	90 days
CTRL	0.075	0.069	0.061
7% RHA	0.054	0.043	0.041
10% RHA	0.043	0.037	0.033
15% RHA	0.038	0.033	0.03

DISCUSSION

Improvements in mechanical and durability properties of the concretes containing RHA can be explained by the chemical and physical effects of RHA. Chemical effect is mainly due to the pozzolanic reactions between the amorphous silica of RHA and calcium hydroxide (C-H) produced by the cement hydration to form calcium-silicate-hydrates (C-S-H). The physical effect which can also be considered as filler effect is that RHA particles increase the packing of the solid materials by filling the spaces between the cement grains in much the same way as cement fills the spaces between fine aggregates, and fine aggregates fill the spaces between coarse aggregates in concrete. Moreover, small particles of additions generate a large number of nucleation sites for the precipitation of the hydration products. This will accelerate the reactions and form smaller C-H crystals. RHA reduces the number of large pores and increases the probability of transforming the continuous pores into discontinuous ones. Therefore, all these mechanisms make the microstructure of the paste more homogeneous and denser.

CONCLUSIONS

Based on the results of the present experiments, the following conclusions can be drawn out:

1) The quality of the RHA cement is widely varied due to the differences in the methods of production. So, it is generally advocated to use special incinerators, which can guarantee controlled burning conditions. With the proper production method, rice husk ash of a pozzolanic reactivity comparable to other pozzolans can be obtained. A special furnace which was designed and constructed was able to produce RHA with various qualities.

2) The duration and temperature of furnace are important parameters, influencing the reactivity of RHA pozzolans. Silica in the rice husk initially exists in the amorphous form, but may become crystalline when rice husk is burnt at high temperature. In addition, silica in rice husk ash will not remain porous and amorphous, when combusted for a prolonged period at a temperature above 650°C, or during less than a few minutes at 1100°C, under oxidizing conditions. The results of XRD analysis show that quartz crystal is present in both types of ashes. So, investigation on the influence of combustion conditions on the amorphous silica suggests that the RHA-650-60 can be considered to be non-crystalline RHA and to save the RHA production time.

3) Huge amounts of crystalline silica or higher carbon content are detrimental to the pozzolanic reactivity of the ash. Presence of un-burnt carbon can adversely affect the reactivity even though it is rich in amorphous silica. The results of pozzolanic activity demonstrate high pozzolanic activity index of produced rice husk ash concrete over that of the control. In addition, the produced rice husk ashes containing up to 90 percent amorphous silica entirely satisfy other requirements of ASTM standard C618-03. This shows the high quality of produced rice husk ashes.

4) The RHA concrete showed higher compressive strength at various ages in comparison with that of the concrete without RHA. In addition, the RHA concrete had higher strength in comparison with that of the concrete without RHA. It is concluded that produced RHA provides a positive effect on the compressive strength of concretes.

5) The performance of concrete with cement replacement by RHA is outstanding considering resistance to water and chloride ion penetration which is in many cases the most important characteristic concerning durability and corrosion prevention.

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