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Strength and Durability of Mortar and Concrete Containing Rice Husk Ash: A Review

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Abstract: The applications of pozzolans in cementitious system are becoming alternative source of cement day by day. This pozzolans contribute in mortar and concrete by two fold of effects, one is filler effect and another is pozzolanic effect. Among pozzolanic materials rice husk ash (RHA) shows good pozzolanic behavior due to its high silica content. The amorphous form of silica found in properly burnt and ground RHA is mainly responsible for pozzolanic reaction. When RHA partially applied in mortar and concrete, the chemical reaction between cement hydration product and silica produced secondary C-S-H gel. As a result, concrete achieveshigher strength due to secondary binder compared to control specimen. The long term sustainability of RHA-mixed concrete and mortar against all negative environmental components is comparatively better than conventional concrete and mortar. A critical review on compressive strength of concrete and mortar incorporating RHA has been described in this paper based on various published literatures. Beside this, durability performance RHA-mixed concrete and mortar such as resistance to chloride, corrosion, sulfate, acid attack, depth of carbonation, water absorption, sorptivity and drying shrinkage are discussed briefly. Furthermore, some recommendations are given for future research. Based on available literature related to the aim it can be concluded that if RHA is replaced up to certain limit then will be an alternate source of binder with better environmental acceptance.

Key words: Rice Husk Ash · Cementitious System · Secondary Binder · Strength · Durability

INTRODUCTION

Production of concrete using Portland cement is popular all over the world. This is due to mainly low cost of materials and construction for concrete structures as well as low cost of maintenance [1]. It is matter of sorrow that, about 4 GJ of energy is required for the finished product during manufacturing of per ton cement. Besides this, it also emits carbon dioxide (CO_2) which is very harmful for the environment. In order to minimize this problem, many researches were performed to find alternative source of cement. From the successful research study, the concept of supplementary cementitious materials is now recognized all over the world [2]. Some of agricultural and industrial waste ash which was fulfilled the criteria as supplementary cementitious materials (SCM). These are rice husk ash, bagasse rice husk wood ash, palm oil fuel ash, fly ash, olive oil ash etc. From past research it is reported that, use of supplementary cementitious materials can improve both strength and durability of cementitious system [3]. The application of SCM is getting priority day by day due to friendly environmental behavior as well as feasible economical aspects [4-7]. Among all of SCM, rice husk ash (RHA) is very potential pozzolans. A huge amount of rice is produced in every year all over the world. As a result a huge amount of rice husk ash received from rice paddy mills as a waste material. The main use of large

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volume of RHA usually discarded into landfills and causing pollution and contamination to water resources randomly [8]. The most potential and effective use of RHA in construction industry have been observed in past studies [9-11]. From the past study, it was found that two types of silica areavailable in RHA. One is amorphous form of silica and another one is crystalline form of silica. Properly incinerated RHA contained about 90% of amorphous silica. This active silica is pmainly responsible for the pozzolanic reaction [12]. When RHA applied in the production of concrete and mortar, total strength increased significantly. This increment of strength was governed by filler and pozzolanic action of fine RHA particles. The filler action RHA is defined as it filled the voids into the mortar or concrete specimen by proper arranging of small particles into specimen and increased compressive strength without any chemical contribution whereas pozzolanic action subjected to series of chemical reaction. The chemical reaction between hydration product of cement and amorphous silica present in RHA produced secondary C-S-H gel which acts as a secondary binder [13-23]. As a result, cementitious system hasbecome more durable, comfortable and strong when RHA applied. Though the early strength of RHA concrete is not good enough than OPC but longer strength is more meaningful [24-31]. From the published literature it is observed that up to 30% replacement of cement by RHA, strength of concrete increased without any adverse effect on strength and durability. This percentage of replacement depends on quality of RHA [32-36]. Some researchers found higher strength for RHA concrete or mortar compared to control specimen at higher replacement of cement [15,36-37]. Concrete and mortar incorporating RHA showed better performance than normal concrete or mortar for long term durability concern. RHA often improve the resistance to corrosion of concretesdue to sulfates and chlorides attack. Even concrete or mortar containing RHAisalso able to resist acid attack from the environment. Considering all durability aspects, RHA improves the quality of concrete significantly. Past research it is proved that, RHA-mixed concrete is more durable than conventional concrete against any negative environmental agents. Even the durability of RHA-mixed concrete or mortar increases with the increment of replacement of cement by RHA. This reason illustrated by the past researchers that when RHA present in cementitious systemit become more compacted with finer RHA as well as reduced the production of cement hydration product. Moreover, RHA preferred by the past researchers as partial replacement of cement in the production of concrete and mortar due to high strength and high durability [11, 34, 36, 38-39]. Based on available published literature, this paper describes typical chemical and physical properties of RHA and its influence on strength development of mortar and concrete incorporating with RHA; long term properties of concrete and mortar associated with RHA. In order to reduce the dependency on cement as well as safety environmental requirements, RHA could be a worthful ingredient as partial replacement of cement.

Properties of RHA: It has been reported that when rice husk is applied in cementitious system, strength and durability increased. This is due to its filler and pozzolanic nature. Pozzolanic effect dominated by pozzolanic reaction which depends on amorphous silica compound. When this amorphous silica gets contact with hydration product of cement then it produces secondary binder. Chemical properties of RHA are presented in Table 1. The table indicates that RHA contained high silica compound and it varies 75-97%. The amount of active silica present in RHA depends on proper burning and grinding. Other chemical compound frequently available less than 1 and total loss of ignition is comparatively low as shown in Table 1. Sometimes uncontrolled burning produced crystalline silica which unable to produce pozzolanic reaction. The presence of amorphous silica and amount of chemical compounds were determined using X-ray diffraction(XRD) and X-ray fluorescence (XRF) test reported in various published literature [32,34-36,40-55]. The filler effect of RHA depends on physical characteristics of RHA. Typical physical properties of RHA and OPC are shown in Table 2 as obtained in various published literature. The table shows that fineness of RHA is the main reason for filler effect because proper ground RHA passed more than 95% through 45 micron sieve normally. As shown in Table 2, specific gravity of RHA is very close to ordinary Portland cements. Higher specific surface area of RHA is another reason for the proper arrangement and densification of microstructure when applied. Therefore, mainly reactive silica compound, large specific surface area and fineness of RHA makes it perfect to use as supplementary cementitious material.

Compressivestrength of Concrete Incorporating RHA: Compressive strength of concrete is increased when RHA partially applied. Compressive strength of concrete as

Table 1: Chemical Properties RHA and OPC

Chemical properties of RHA										
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	P_2O_5	LOI	References
77.19	6.19	3.65	2.88	1.45	-	0.00	1.815	1.10	5.42	[40]
87.20	0.15	0.16	0.55	0.35	0.24	-	-	-	5.44	[41]
90.90	0.83	0.6	0.8	0.56	-	-	-	-	-	[34]
89.87	0.14	o.94	0.49	-	-	0.25	2.16	-	4.81	[43]
91.00	0.35	0.41	-	0.81	1.21	0.08	3.21	0.98	8.50	[32]
94.84	0.39	0.54	1.32	0.40	0.01	0.11	1.45	-	0.25	[45]
88.32	0.46	0.67	0.67	0.44	-	-	2.91	-	5.81	[46]
73.60	0.07	0.26	0.76	0.27	-	0.09	1.17	-	22.90	[47]
89.47	Traces	0.62	2.69	1.16	0.93	2.09	0.83	-	2.27	[48]
90.00	0.28	0.14	0.45	0.28	0.02	0.08	1.55	-	5.00	[35]
89.61	0.04	0.22	0.91	0.42	-	0.07	1.58	-	5.91	[61]
87.46	2.53	0.40	0.78	1.58	-	-	4.73	-	2.52	[50]
87.20	0.15	0.16	0.55	0.35	0.24	1.12	3.68	-	8.55	[51]
93.20	0.40	0.10	1.10	0.10	0.90	0.10	1.30	-	3.70	[36]
97.53	-	0.21	0.22	-	-	0.01	0.04	0.26	1.72	[65]
90.00	0.50	0.90	0.80	0.60	0.10	0.10	2.10	-	3.20	[60]
87.20	0.15	0.16	0.55	0.35	-	1.12	3.60	-	6.55	[54]
86.98	0.84	0.73	1.40	0.57	-	0.11	2.46	-	5.14	[55]
Chemical properties of OPC										
17.00	3.90	3.20	70.0	1.50	3.60	0.02	0.53	-	0.25	[42]
21.27	6.19	3.64	65.2	-	-	0.19	0.71	-	1.53	[43]
19.59	4.79	3.07	64.35	1.69	2.75	0.07	0.98	-	2.09	[35]
20.99	6.19	3.86	65.96	0.22	-	0.17	0.6	-	1.73	[49]

Table 2: Physical properties of RHA and OPC

Physical Properties of RHA						
Specific gravity	Bulk density (kg/m^3)	Fineness passing 45 micron(%)	Nitrogen absorption fineness (m^2/kg)	Blaine specific surface area (m^2/kg)	BET surface area (m^2/g)	References
2.06	718.0	96.0	-	-	-	[41]
-	429.1	-	-	-	-	[34]
2.03	-	-	23455	-	-	[43]
2.07	-	-	-	2330	-	[44]
2.19	-	99.5	-	2226	50.2	[48]
2.15	-	-	-	360	-	[61]
2.06	-	99.0	38.9	-	-	[51]
2.20	-	-	-	-	93.6	[65]
2.06	-	-	28800	-	-	[54]
Physical Properties of OPC						
3.12	-	-	-	328	-	[43]
3.11	-	-	-	324	-	[39]
3.14	-	-	-	309	-	[38]
3.09	-	-	-	373	-	[51]

Table 3: Compressive strength of concrete with and without RHA

		Compressive strength (Mpa)					
RHA:OPC	W/B ratio	7 days	14 days	28 days	56 days	90 days	References
10:90	0.23	62	63	66	69	74	[32]
00:100	0.35	50	54	56	60	67	
10:90	0.35	47	52	61	62	67	
20:80	0.35	47	52	60	61	69	
30:70	0.35	43	51	54	60	64	
10:90	0.47	37	40	47	51	56	
00:100	0.53	30.2	-	39.6	-	-	[46]
05:95		30.0	-	40.2	-	-	
10:90		34.3	-	48.4	-	-	
15:85		31.3	-	42.4	-	-	
20:80		29.8	-	40.6	-	-	
00:100	0.53	27.22	33.29	36.45	-	-	[11]
05:95		31.32	35.62	36.49	-	-	
10:90		30.45	35.97	37.43	-	-	
15:85		31.52	35.04	37.38	-	-	
20:80		31.64	36.17	37.71	-	-	
25:75		33.09	35.27	39.55	-	-	
30:70		33.53	35.44	37.80	-	-	
00:100	0.30	53.6	-	63.5	-	71.7	[55]
10:90	0.30	60.6	-	72.8	-	83.2	
15:85	0.30	62.5	-	75.1	-	84.9	
20:80	0.30	64.3	-	78.2	-	86.8	
00:100	0.32	51.0	-	59.6	-	66.8	
10:90	0.32	58.0	-	68.8	-	78.2	
15:85	0.32	61.2	-	72.2	-	81.5	
20:80	0.32	61.8	-	72.7	-	82.2	
00:100	0.34	49.8	-	57.9	-	64.9	
10:90	0.34	56.8	-	66.6	-	75.6	
15:85	0.34	57.6	-	67.2	-	75.8	
20:80	0.34	59.1	-	69.3	-	77.2	
0:100	0.53						
	-	-	35.4	-	-	[62]	
5:95		-	-	33.6	-	-	
10:90		-	-	32.4	-	-	
15:85		-	-	32.1	-	-	
20:80		-	-	30.8	-	-	
25:75		-	-	29.7	-	-	
30:70		-	-	26.6	-	-	
00:100	0.35	-	-	53.7	-	67.9	[35]
	0.50	-	-	47.3	-	51.4	
	0.65	-	-	27.6	-	35.0	
10.90	0.35	-	-	68.1	-	76.4	
	0.50	-	-	46.9	-	62.1	
	0.65	-	-	31.7	-	38.6	
20:80	0.35	-	-	72	-	85.6	
	0.50	-	-	52.3	-	62.9	
	0.65	-	-	33.2	-	41.7	
30:70	0.35	-	-	67.4	-	78.9	
	0.50	-	-	50.1	-	65.1	
	0.65	-	-	29.9	-	37.3	
00:100	0.53	30.2	-	39.6	-	44.1	[49]
20:80	0.53	32.1	-	41.7	-	47.3	

Table 3: Continue

RHA:OPC	W/B ratio	Compressive strength (Mpa) 7 days	14 days	28 days	56 days	90 days	References
00:100	0.35	77.9	-	86.5	-	91.9	[53]
05:95	0.35	83.6	-	93.7	-	95.8	
10:90	0.35	88.8	-	98.5	-	107.8	
00:100	0.35	-	-	64.0	-	68.8	[15]
12.5:87.5		-	-	68.4	-	73.2	
25:75		-	-	75.6	-	79.4	
50:50		-	-	44.3	-	69.5	
00:100	0.32	48.4	-	55.5	-	60.6	[56]
	0.40	35.8	-	42.3	-	45.6	
	0.50	24.6	-	32.9	-	35.9	
10:90	0.32	51.1	-	60.4	-	64.3	
	0.40	41.1	-	50.4	-	54.9	
	0.50	24.1	-	31.5	-	35.5	
20:80	0.32	44.3	-	54.8	-	62.7	
	0.40	27.9	-	40.7	-	51.4	
	0.50	24.9	-	34.9	-	37.9	

obtained from various published literatures is shown in Table 3. Hwang *et al*. [32] reported that, RHA-mixing concrete showed lower strength than control concreteat early age. Concrete with 20%RHA showed higher compressive strength than control specimenat 56 and 90 days. This was due to action of secondary C-S-H gel with complete formation and also compacted structure with small RHA particles. Gastaldini *et al.* [35] reported that, concrete at higher replacement of cement with RHA, showed more strength than control concrete at long term curing.Highest strength was 85.6 MPa at 20% replacement of cement with a w/c ratio 0.35. Strength of RHA concrete is dependent on curing period, w/c ratio and replacement level. De Sensale [56] used two types RHA, one was residual RHA and another was control incinerated RHA. The author reported that, residual RHA was good for filler action whereas control burned RHA was active in both filler and pozzolanic action. For longer period control incinerated RHA showed significant strength than control concrete when 20% cement was replaced by RHA a with w/c ratio 0.32. According to Habeeb *et al.* [46], the replacement of cement was 5% to 20% by RHA. They found that, at 5% replacement level showed slightly higher compressive strength than control mixture. The author also reported that, compressive strength was higher due to the increment of reactivity and the filler effect of RHA. On the other hand,available silica from the addition of 5% RHA reacted with only a small portion of C-H released from the hydration process and thus, the C-S-H released from the pozzolanic reaction. The strength increased with RHA for up to 10% which resulted in achieving the maximum value where the strength of concrete at 20% replacement of OPC by RHA achieved equivalent values to the strength of control concrete. Saraswathy *et al.* [11] reported that upto 30% replacement level of RHA, there is no decrease in compressive strength observed when compared to conventional OPC concrete at 7 to 28 days curing period. However, author concluded that at 25% replacement of cement by RHA considerable strength and durability of concrete were found. Even RHA specimens (20% cement replaced) was given lower strength with compared to control specimens at short term ages but in the long term studies indicate the strength of RHA-mixed concrete was comparable to normal concrete at the ages of 270 days reported by Babaiefar *et al.* [62]. According to Isaia *et al.* [15] study, cement was replaced up to 50% by RHA. They were found that, the strength of RHA concrete showed higher strength over control concrete in both 28 and 90 days curing period when cement was replaced by 25% RHA. Moreover, concrete incorporating 50% RHA showed higher strength at 90 days than control specimens. From above discussions it is proved that strength of RHA associated concrete increases up to 30% replacement of cement. Though early strength development concrete with percentages RHA is not good but long term strength shows significant results.

Compressive Strength of Mortar Containing RHA: The strength development with ages is the common feature of pozzolanic materials. At 20% replacement, thestrengths of mortars containing RHA showed maximum strength value. However, the mortars containing 40% RHA showed lower strength than control at 28 days

Table 4: Compressive strength of mortar and paste influenced by RHA

\RHA:OPC	W/B ratio	Compressive strength (Mpa) 1 day	3 days	7 days	28 days	90 days	References
00:100		-	-	43.5	57.0	60.0	[36]
20:80	0.50	-	-	44.5	58.5	62.5	
40:60		-	-	33.5	55.0	62.0	
00:100	0.53	11.6	20.9	27.2	37.0	-	[3]
05:95		12.0	22.1	27.4	38.9	-	
10:90		12.8	24.4	27.8	42.8	-	
15:85		13.8	28.9	29.3	46.7	-	
20:80		12.2	24.8	28.3	39.8	-	
25:75		11.7	23.6	27.6	38.3	-	
30:70		11.1	20.7	27.4	37.0	-	
35:65		10.4	18.4	26.4	36.0	-	
00:100	0.50	-	27	32.9	42.9	48.3	[37]
30:70		-	32.3	46.1	59.5	64.7	
50:50		-	26.5	39.6	58.3	61.5	
70:30		-	24.3	35.9	43.3	50.8	
Compressive strength of paste matrix using RHA							
00:100		52.6	-	88.9	100.5	-	[52]
05[a]:95		41.1	-	80.8	100.5	-	
10[a]:90	0.30	48.3	-	86.7	105.5	-	
05[b]:95		37.6	-	70.6	85.9	-	
10[b]:90		39.7	-	83.3	97.4	-	

a residual RHA from rice mill; b RHA produced by controlled incineration.

while 90 days curing strength higher than control strength at same replacement level [36]. Table 4 represents the value of compressive strength of mortar and paste which were determined by various past researchers. Ganesan *et al.* [3] used RHA up to 35% replacement of cement to make mortar specimens. The author concluded that, up to 30% cement can be replaced by rice husk ash without any adverse effect on strength and durability properties. The maximum strength gained at 28 days with 15% RHA. High specific surface area and the presence of reactive silica in RHA influenced to the pozzolanic reaction that is why strength increased as reported by the author. Mehta [37] prepared mortar using Portland-RHA cement where cement was replaced at 30%, 50% and 70% by RHA. Mortar cube specimens were tested at 3, 7, 28, 90 days curing. According to his study, highest strength obtained when cement replaced 30% by RHA. Moreover, compressive strength of mortars was greater than control mortars up to 70% replacement level at 7 to 90 days. But early strength development of Portland-RHA cement was not satisfactory. On the basis of strength data, the author treated RHA an exceptionally reactive silica material. De Sensale *et al.* [52] prepared paste matrix with two types of RHA, highest strength was found at 28 days for 10% residual RHA collected from rice mills. However, early strength development of controlled incineration RHA is better than residual RHA. Therefore, cement can be replaced more than 30% without effecting strength of mortar. The difference of strength between RHA mixed mortar and control mortar is much higher at long term ages.

Durability of Concrete and Mortar Incorporating RHA

Resistance to Chloride Attack: The main feature of chloride attack in concrete is deterioration of embedded steel due to action of chlorides which cause serious damage. In order to determine resistance to chloride attack in RHA-added concrete different researchers performed various experimental investigations. Madandoust *et al.* [34], conducted chloride attack test according to ASTM C1152 and prepared 100 mm cube and 100mm×50mm beam of mconcrete specimens. In order to test, the locations were selected at various depths 0-10 mm, 10-20mm, 20-30mm and 30-40 mm at 360days over the samples. Concretes containing higher RHA content, the lower the chloride concentration was appeared across the specimensas reported by the author where cement was replaced by RHA from 15 to 25%. The control specimens had significantly higher chloride concentrations at any particular depth compared with specimens containing RHA. This better performance of RHA concretes against chloride penetration over the control specimens due to less porosity and finer pore structures obtained from RHA concrete specimens. De Sensale [38] cast concrete specimen sizes 100mm×200mm at various w/(c+RHA) ratio of 0.50,0.40,and 0.32 followed to Italian standard 79-28for testing chloride attack. Based on experimental results, the author concluded that lower depth was found for higher replacement of cement by RHA where cement was replaced (0-15%) by RHA for all cases. Horsakulthai *et al.* [59] described accelerated chloride migration test as per AASHTO T259 for cylindrical concrete specimen of 100mm dia and 200 mm height. A potential of 60Volt direct current was passed across the prepared concrete cylinders (50mm thick slices and the 50mm ends) after 28 days to accelerate chloride penetration into concrete specimens. For a time being when specimen was split into two halves and 0.1 N $AgNO_3$ solution was sprayed to measure the chloride penetration depth for control and baggase rice husk wood ash (BRWA) concrete. The depth of chloride penetration for control concrete specimen was higher than 10-40% BRWA concrete. Similar research was carried by Chindaprasirt *et al.* [36] for rapid chloride penetration test (RCPT) in accordance with the method described in ASTM C1202. The authors reported that, 7450 Coulombcharge passed throughnormal OPC andsubstantially is reduced with incorporation of pozzolans as compared to of normal mortar. The incorporation of 20% and 40% of FA reduced the charge passed to 3050 and 1950 Coulomb whereas POFA reduces the charge passed to 1900 and 1050 Coulomb at same replacement levels. RHA was the most effective and reduced the charge passed to 750 and 200 Coulomb at 20% and 40% replacement levels shown in Table 5. Saraswathy *et al.* [11] also conducted rapid chloride penetration test as per ASTM C1202-94 for concrete disc of size 85 mm diameter and 50 mm thickness. Concrete specimens were cast up to 30% replacement of cement by RHA and after 28-dyays curing these were subjected to rapid chloride penetration test by applying 60 Volt. Two halves of the specimen was sealed with PVC container of diameter 90 mm and one side of the container was filled with 3% NaCl solution which was connected to the negative end of the power supply whereas the other side was filled with 0.3 N NaOH solution which wasconnected topositive end of the power supply. Current was recorded at every 30 minutes up to 6 hours in order to measure chloride permeability which was calculated in terms of Coulombs at the end of 6 hours. The lowest and highest charge passed in coulombs reported by the author for 30% RHA concrete and control specimen respectively. From test results, as shown in Table 5, it is observed that highest charge passed for OPC where lowest charge passed for 30% RHA specimen.

Table 5: Resistance to chloride ions of rice husk ash replaced concrete

Replacement OPC (%)	Charge passed (Coulombs)	References
0	1161	[11]
5	1108	
10	653	
15	309	
20	265	
25	213	
30	273	
0	7450	[36]
20	750	
40	200	

Similar results were reported by Nehdi *et al.* [33] using various types of RHA with replacements 7.5-12.5% of cement. For all types of RHA concrete, charges passed less than control concrete. It is clear from above discussion that concrete and mortar mixed with RHA shows satisfactory performance against chloride attack. This performance is increasing with increasing of percentages replacement.

Performance Against Corrosion: Corrosion of reinforcing steel and other embedded metals is the leading cause of deterioration in concrete which reduce the concrete strength and longevity. Normally, corrosion occurred in concrete due to various chemicals and atmospheric condition of environment. In order to test corrosion performance of concrete, Saraswathy *et al.* [11] cast cylindrical concrete specimens (50mm diameter and 100mm height) using 1:1.50:3.0 mix ratio (w/c = 0.53) with centrally embedded rebar of 12 mm diameter and 100 mm height. Ordinary Portland cementwas replaced by RHA at 5%, 10%, 15%, 20%, 25% and 30% to prepare specimens. In the aim of corrosion test after 28 days curing, cylindrical specimens were subjected to impressed voltage test. Then concrete specimens were immersed in 5% NaCl solution and embedded steel in concrete wasmade anode with respect to an external stainless steel electrode acted as cathode by applying a constant positive potential of 12 Volt to the entire system from a DC source. They reported that, no cracks found even after 144 h of exposure in higher replacement percentages (15%, 20%, 25% and 30%) of Portland cement by RHA. However, the concrete specimens containing lower content (5% and 10%) of RHA also failed within 72 and 74 hours of exposure whereas ordinary Portland cement concrete specimenwas cracked even after 42 h of exposure in 5% NaCl solution. The author concluded that, the replacement of rice husk ash filled the pores into the microstructure as a result the permeability and corrosion gets reduced. Similar investigation was described by

Horsakulthai *et al*. [59] in accordance with the NT BUILD 356. This test conducted at 90 days curing of specimens using 5V direct current with 3% NaCl solution by weight of solution. The initial crack time listed in literature for Portland cement,10%, 20% and 40% bagasse rice husk wood ask (BRWA) concretes were 15, 31, 55 and 67 days respectively when w/c ratio 0.60. From the test results it was clear that the increase of replacement percentages of BRWAincreased thetime of initial crack. On the other hand for 20% BRWA concrete with a w/c ratio 0.45, no cracking was observed evenafter 90 days exposure. The low w/c ratio and high percentages BRWA blended cement concrete significantlyimproved the resistance to corrosion. Though corrosion is very harmful and common in concrete but corrosion can be easily defended by using RHA in the manufacture of concrete.

Resistance to Acid Attack: Mortars and concrete have superior durability in acidic environmental conditions. Mehta [37] made concrete cylinders with 0.4 w/c ratio using both Type II Portland cement and Portland-RHA cement which containing 35% RHA by weight. The specimens were submerged continuously for a period of 1500 hours in 5% both of HCl and H_2S0_4 solution. The total weight loss for Portland cement concrete registered 35% whereas the Portland-RHA cement concrete showed only 8% weight loss during specimens were in the 5 % HCl solution. Similar type of result recorded for the 5% H_2SO_4 solution where it was found 27% weight loss for the Portland cement concrete and 13% for the Portland-RHA concrete. The author interpreted the results by this way that, Portland cements contain 60-65% CaO and their hydration products contain about 25% $Ca(OH)_2$, which is primarily responsible for the poor resistance of Portland cement concretes exposed to acidic attack. However, cement incorporating RHA may have 20-40%CaO and practically no $Ca(OH)_2$ in the products of hydration. Chatveera *et al.* [39] prepared 100mm×100mm×100mm concrete specimens with black rice husk ash (BRHA) in order to test the effect the resistance against acid attack. When specimens reached 28 days age then took the initial weights and then shifted to 1% solution of hydrochloric (HCl) acid and the same amount of 1%solution of sulfuric (H_2SO_4) acid. When concrete exposed to HCl and H_2SO_4 attacks at replacement of 20% of Portland cement by (BRHA), specimens showed satisfactory performance in decreasing the corrosion of concrete under both HCl and H_2SO_4 attacks. Even at replacement of 40% of Portland cement by BRHA was able to resist HCl attack, but it was not suitable against H_2SO_4 attack. The chemical compositions in concrete mix proportion are an important factor for the damage of concrete due to acid attack. The lowest weight loss of concrete reported by the author due to HCl and H_2SO4 attacks when Portland cement was replaced 20% by BRHA. Similarly, De Sensale [38] followed ASTM C267 to test mortar cylinders of 50mm×100mm and specimens were exposed in 1% HCl solution. The mass was determined up to 84 days and the specimens containing RHA found to be more resistant to HCl attack than the specimens without RHA. They concluded that the mass loss decreases with the increasing of RHA content in mortars. Therefore, presence of RHA in concrete makes it more suitable in acidic environment.

Sulfate Resistance: The sulfate attack is very common and harmful for concrete and mortar. The sulfate containing salts, such as calcium, magnesium, sodium and potassium sulfates compounds are responsible for sulfate attack, because, these are capable of chemically reacting with components of concrete. The mechanism of sulfate attack was described by Santhanam *et al*. [63-64] due to sodium sulfate. They mentioned that when mortars exposed to sodium sulfate solution then calcium hydroxide from the hydration reaction of cement reacts with sodium sulfate and transformed to gypsum, leading a change of an outer skin of the specimen due to the expansion.Then gypsum reacts with the aluminum compounds to produce ettringite that increases in volume and instability. This expansion of cement matrix is responsible for leading to further cracking of the interior of the mortar. The equations are given below:

$$Ca(OH)_2 + Na_2SO_4 \rightarrow CaSO_4 + NaOH$$

(First expansion)

$$CaSO_4 + Alu\min umcompounds \rightarrow Ettringite$$

(Second expansion may cause carck)

Chatveera *et al*. [7] reported the length change due to sulfate attacks in accordance with ASTM C1012 (2002) by using 25×25×285 mm bars where sand-to-binder materials ratio of 2.75 by weight. The measurements of length change were takenusing digital length comparator at the age of 1, 2, 3, 4, 8, 13, 15, 17, 19, 21, 23 and 25 weeks. For the durability against sulfate attack, mortar exposed to both magnesium sulfate ($MgSO_4$) and sodium sulfate (Na_2SO_4) solution. For both cases mortar showed positive effect against expansion of mortar. Even higher replacement rate 30-50% black rice husk ash mortars were comparable to the sulfate resistant mortars by considering expansion values. The loss of strength reduced with the increment replacement percentages when mortars exposed to magnesium sulfate ($MgSO_4$) solution.Moreover, the strength loss of mortars containing rice husk ash was lower than OPC mortars when mortars exposed to magnesium sulfate ($MgSO_4$) solution reported by the author. Chindaprasirt *et al.* [60] performed sulfate-induced expansion test according to ASTM C1012 using 5% sodium sulfate solutionand mortar specimens prepared according to ASTM C109. The author concluded from the compressive strengths at 7, 28, 90 and 180 days that, the incorporation of lignite class F fly ash and ground RHA into normal Portland cement result in a high improvement in the resistance to attack by 5% sodium sulfate solution. Better dimension stability wasgained with blended cements containing FA and RHA. Sulfate resistancewas very effective for RHA at a dosage up to 40% cement replacement where Class F lignite fly ash comparatively less effective at both 20% and 40% replacement levels. This was due to lower water demand characteristics of RHA. Another reason to resist sulfate attack, fly ash and RHA mortar showed of lower pH levels after a particular time period. In order to confirm the experimental results the author done SEM testfor OPC mortars as well as pozzolanic mortars. It was seen that the formation of ettringite was less sound in pozzolanic mortars exposed to sodium sulfate solution. Finally, the author suggested that up to 40% of Portland cement could be replaced with fly ash and RHA in making blended cement mortar with reasonable strength development and excellent sulfate resistance. De sensale [38] tested sulfate attack for mortars specimen (25mm × 25mm × 285mm) by following ASTMC 1012. The author concluded that the rise in sulfate resistance of RHA with increasing RHA replacement level after 28 weeks curing period. It can be summarized that, sulfate resistance of RHA concrete much better than control concrete due to pozzolanic and physical effect of RHA.

Depth of Carbonation: Carbonation shows a positive effect for concrete and mortar by increasing both tensile and compressive strength. A brief description of the mechanism of carbonation is as follows. At first CO_2 dissolves in water and formed carbonic acid (H_2CO_3). A chemical reaction between hydration production of cement ($Ca(OH)_2$) and carbonic acid leads to form calcium carbonate ($CaCO_3$) which is responsible for corrosionof the embedded steel in concrete. But if cement is replaced by RHA or any other pozzolans then the cement hydration product reduced as well as porosity of concrete increased which infiltrate the CO_2. The hydrated C-S-H gel also generates carbonate by leaving calcium oxide (CaO) [66-68]. Chatveera *et al*. [39] cast 100mm concrete cube to examine long term carbonation test. After 28 days curing period specimens were transferred to carbonation chamber with 0.03% CO_2 content up to 180 days. Then depth of carbonation measured using carbonation indicator. The author reported that, the depth of carbonation increased with increasing of percentage replacement of black rice husk ash. From his study it was clear that the carbonation performance of concrete increased when concrete incorporating with RHA. Gastaldini *et al*. [66] tested role of chemical activators on the carbonation of concrete containing 20% RHA. But the author found lowest carbonation coefficient for the mixture of 20% RHA and 1% K_2SO_4. Moreover, presence RHA in concrete increases the carbonation performance.

Water Absorption and Sorptivity: RHA improves the durability of concrete by reduction of water absorption and sorptivity significantly. Saraswathy *et al.* [11] performed water absorption test according to ASTM C642-97 for concrete containing RHA up to 30%. The author reported that, co-efficient of water absorption reduced when concrete incorporating with RHA in all percentages replacement. Ganesan *et al.* [3] measured water absorption and sorptivity values after 28 and 90 days moisture curing. The author also found progressively lower coefficient of water absorption with the increment of RHA content compared to control specimens. Similar results were observed for sorptivity test. Mahmud *et al*. [71] cast cylindrical concrete specimens of 100mm×200mm to test water absorption and sorptivity of RHA blended concrete. The author concluded that, water absorption and sorptivity reduced presence of RHA in concrete. This reason illustrated in Da Silva *et al.* [65], as when RHA present in concrete specimen it reduces the inside pores as well as makes in uniformly arranged by finer RHA particles. As a result, the water absorption and sorptivity reduced than control concrete. Givi *et al*. [58] reported that, the water absorption co-efficient lower for ultrafine RHA (average particle size 5 μm) replaced concrete than control concrete up to 20%. However, RHA (average particle size 95 μm) concrete showed greater water absorption value than

Table 6: Water absorption and sorptivity of RHA blended concretes

Replacement OPC (%)	Coeff. of water absorption × 10^{-10} (m^2/s) 28 days	90 days	Sorptivity ×10^{-6} ($m/s^{1/2}$) 28 days	90 days	References
0	1.62	0.85	11.05	9.76	
5	1.42	0.71	10.60	7.09	
10	1.03	0.61	9.16	4.86	
15	0.99	0.46	7.37	4.09	
20	0.92	0.31	6.00	3.61	[3]
25	0.51	0.20	5.53	2.28	
30	1.06	0.43	6.08	3.38	
35	1.51	0.58	10.30	4.04	
0	3.5571	-	-	-	
5	0.67587	-	-	-	
10	0.10320	-	-	-	
15	0.10644	-	-	-	[11]
20	1.2122	-	-	-	
25	1.4548	-	-	-	
30	1.3030	-	-	-	
0	2.86	1.35	-	-	
5	2.98[a]	1.25[a]	-	-	
10	2.96[a]	1.13[a]	-	-	
15	3.10[a]	1.25[a]	-	-	
20	3.24[a]	1.32[a]	-	-	[58]
5	2.47[b]	1.03[b]	-	-	
10	1.97[b]	0.89[b]	-	-	
15	2.55[b]	1.12[b]	-	-	
20	2.57[b]	1.20[b]	-	-	
0	-	-	9.166	7.1	
10	-	-	8.649[c]	6.58[c]	[71]
10	-	-	10.47[d]	12.7[d]	

a-average particle size 95 µm; b-average particle size 5 µm; c-water reduced concrete; d-normal concrete

OPC. Therefore, fineness of RHA is responsible to reduce water absorption through the system. Safiuddin *et al* [44] described that, water absorption of the concretes reduced with a greater RHA content because porosity of concrete reduced at higher RHA concrete. Table 6 represents the water absorption and sorptivity values for RHA mixed concretes from various literature. Therefore, presence of RHA in concrete leads to a lower water absorption and sorptivity which is important factor for long durability concern.

Drying Shrinkage: Drying Shrinkage is occurred due to loss of capillary water by the reduction of structure. As a result, drying shrinkage often causes in concretecracking and internal warping prior of loading. Chatveera *et al*. [39] performed drying shrinkage test according to Japan Concrete Institute (JCI, 1998) for concrete specimens of 100mm × 100mm × 500mm. The author reported that, higher percentages (20-40%) RHA concrete showed comparable drying shrinkage to the control concrete because of packing effect of RHA particles. However, Habeeb and Fayyadh [69] reported that, drying shrinkage of RHA mixed concrete greater than OPC concrete where 20% cement was replaced by RHA. Mahmud *et al*. [70] cast 105mm×300mm cylindrical concrete to measure drying shrinkage according to ASTM C (531-85). The author reported that, higher amount RHA in concrete showed lower drying shrinkage value. Similarly, Wu and Peng [71] reported that, in normal temperature drying shrinkage of RHA mixed concrete less than pure cement concrete. Zhang and Malhotra [72] found similar drying shrinkage for control concrete and 10% RHA concrete after 448days. It can be concluded that, drying shrinkage performance is not good for high percentages RHA blended concrete due to reduction of cement and pore structure.

Recommendations for Future Research: RHA can be used as a supplementary cementing material up to 30% replacement of cement without causing any negative effect on the strength and durability of mortar and concrete. RHA contributes to the cementitious system by filler and pozzolanic action. The exact contribution of each particular effect did not measure by the past research. In order to commercial use of RHA globally, each effect should be identified. Research need with higher percentages RHA amount present in concrete and mortar. Following recommendations for future work with RHA have been identified from the current study.

- To investigate the physical and chemical effect of RHA in cementitious system.
- To prepare a comparative cost analysis between concrete with and without RHA.
- Long-term strength and durability should be measured; for example 180 days, 1 year.
- Strength for higher replacement of cement with RHA should measure.
- To investigate an alternative source of binder using RHA and other pozzolans with chemical activators.

Concluding Remarks: In order to preserve energy and reduce carbon dioxide, RHA play an important role when added to Portland cement. A large volume of RHA is generated from rice milling industries every year. The proper use of RHA in construction industry could develop a healthy and sustainable environment. RHA is very effective in partial replacement of cement (30% or more) to produce higher compressive strength concrete and mortarover OPC. Strength of cementitious system incorporating with RHA influencesby the combined action of filler and chemical effect of RHA. The durability performance of RHA concrete and mortar is also highly noticeable even in higher replacement of cement (more than 40% replacement) by RHA. As results, the presence of RHA in cement and concrete has gained considerable importance because of the requirements of environmental safety and more durable construction in the future.

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REFERENCES

1. Mehta, P.K., 1999. Concrete Technology for Sustainable Development. Concrete International, 21(11): 47-52.
2. Molhotra, V.M., 1993. Fly Ash, Slag, Silica Fume and Rice Husk Ash in Concrete: A review, Concrete International, 15(4): 2-28.
3. Ganesan, K., K. Rajagopal and K. Thangavel, 2008. Rice Husk Ash Blended Cement: Assessment of Optimal Level of Replacement for Strength and Permeability Properties of Concrete. Constructionand Building Materials, 22(8): 1675-1683.
4. Coutinho, J.S., 2005. The combined benefits of CPF and RHA in improving the durability of concrete structures. Cement and Concrete Composites, 25(1): 51-59.
5. Ikpong, A. and D. Okpala, 1992. Strength characteristics of medium workabilityordinary Portland cement-rice husk ash concrete. Building and Environment, 27(1): 105-111.
6. Cordeiro, G., R. Filho, L. Tavares and E. Fairbairn, 2009. Ultrafine grinding of sugarcane bagasse ash for application as pozzolanic admixture in concrete. Cement and Concrete Research, 39(2): 110-115.
7. Chatveera, B. and P. Lertwattanaruk, 2009. Evaluationof Sulfate Resistance of Cement Mortars ContainingBlack Rice Husk Ash. Journal of EnvirontalManagement, 90(3): 1435-1441.
8. Mehta, P.K., 1997. Durability: Critical Issues for the Future. Concrete International, 19(7): 69-76.
9. Nehdi, M., J. Duquette and A. El-Damatty, 2003. Performance of rice husk ash producedusing a new technology as a mineral admixture in concrete. Cement and Concrete Research, 33(8): 1203-1210.
10. Chindaprasirt, P. and S. Rukzon, 2008. Strength, porosity and corrosion resistance ofternary blend Portland cement, rice husk ash and fly ash mortar. Construction and C Building Materials, 22(8): 1601-1606.
11. Saraswathy, V. and H. Song, 2007. Corrosion Performance of Rice Husk Ash Blended Concrete. Construction and Building Materials, 21(8): 1779-1784.
12. Jamil, M., A.B.M.A. Kaish, S.N. Raman and M.F.M. Zain, 2013. Pozzolanic contribution of rice husk ash in cementitious system, Construction and Building Materials, 47: 588-593.
13. Karim, M.R., M.F.M. Zain, M. Jamil and F.C. Lai, 2013. Fabrication of anon-cement composite binder by using slag, palm oil fuel ash and rice huskash with sodium hydroxide as an activator. Construction and Building Materials, 49: 894-902.
14. Zain, M.F.M., M.N. CIslam, F. Mahmud and M. Jamil, 2011. Production of rice husk ash for use in concrete as a supplementary cementitious material. Construction and Building Materials, 25(2): 798-805.
15. Isaia G.C., A.L.G. Gastaldini and R. Moraes, 2003. Physical and pozzolanic action of mineraladditions on the mechanical strength of high-performance concrete.Cement Concrete Composites, 25(1): 69-76.
16 Detwiler, R.J. and P.K. Mehta, 1989. Chemical and physical effects of silica fume on themechanical behavior of concrete. ACI Mater Journal, 86(6): 609-14.
17 Cheerarot, R., J. Tangpagasit and C. Jaturapitakkul, 2004. Compressive Strength of Mortars Due to Pozzolanic Reaction of Fly Ash.ACI Journal. Special Publication, 221: 411-426.
18 Tangpagasit, J., R. Cheerarot, C. Jaturapitakkul and K. Kiattikomol, 2005. Packing effect and pozzolanic reaction of fly ash in mortar.Cement Concrete Research, 35(6): 1145-1151.
19. Cordeiro, G.C., R.D. Toledo Filho, L.M. Tavares and E.M.R. Fairbairn, 2008. Pozzolanic activity and fillers effect of sugar cane bagasse ash on Portland cement and limemortars. Cement Concrete Composites, 30(5): 410-8.

20. Jaturapitakkul, C., J. Tangpagasit, S. Songmue and K. Kiattikomol, 2011. Filler effect and pozzolanic reaction of ground palm oil fuel ash. Constrstruction and Building Materials, 25(11): 4287-4293.
21. Khan, M.N.N., M. Jamil, A.B.M.A. Kaish, M.F.M Zain and M.R. Karim, 2014. An Experimental Study on theStrength of Mortar due to Filler Effect of Pozzolanic Materials. International Journal of Advanced Structures and Geotechnical Engineering, 3(2): 106-109.
22. Goldman A. and A. Bentur, 1993. The influence of microfillers on enhancement of concrete strength. Cement Concrete Research, 23(4): 962-72.
23 Goldman, A. and A. Bentur, 1994. Properties of cementitious systems containing silica fume or nonreactive micro fillers. Advanced Cement Based Materialsl, 1(5): 209-15.
24 Della, V.P., I. Kuhn and D. Hotza, 2002. Rice husk ash as analternate source for active silica production. Materials Letters, 57(4): 818-821.
25. Feng, Q., H. Yamamichi, M. Shoya and S. Sugita, 2004. Study on the pozzolanic properties of rice husk ash by hydrochloric acid pretreatment. Cement and ConcreteResearch, 34(3): 521-526.
26. Mehta, P.K. and P.C.C Aitcin, 1990. Principles Underlying Production of High-Performance Concrete. Journal of Cement, Concrete and Aggregates, 12(2): 70-78.
27. Givi, A.N., S.A. Rashid, Farah Nora A. Aziz and M.A.M. Salleh, 2010. Contribution of Rice Husk Ash to the Properties of Mortar and Concrete: A Review. Journal of American Science, 6(3): 157-165.
28. Zhang, M.H., R. Lastra and V.M. Malhotra, 1996. Ricehuskash paste and concrete: Some aspects of hydrationand the microstructure of the interfacial zone between theaggregate and paste. Cement and Concrete Research, 26(6): 963-977.
29. Karim, M.R., M.F.M. Zain, M. Jamil, F.C. Lai and M.N. Islam, 2012. Strength of Mortar and Concrete as Influenced by Rice Husk Ash: A Review. World Applied Sciences Journal, 19(10): 1501-1513.
30. Yu, Q., K. Sawayama, S. Sugita, M. Shoya and Y. Isojima, 1999. The reaction between rice husk ash and $Ca(OH)_2$solution and the nature of its product. Cement andConcrete Research, 29(1): 37-43.
31. Nicole, P.H., P.J.M. Monteiro and H. Carasek, 2000. Effect of Silica Fume and Rice Husk Ashon Alkali-Silica Reaction. Materials Journal, 97(4): 486-492.
32. Hwang, C.L., Bui Le Anh-Tuan and Chen Chun-Tsun, 2011. Effect of rice husk ash on the strength and durability characteristics of concrete, Construction and Building Materials 25(9): 3768-3772.
33. Nehdi, M., J. Duquette and A. El Damatty, 2003. Performance of rice husk ashproduced using a new technology as amineral admixture in concrete Cement and Concrete Research, 33(8): 1203-1210.
34. Madandoust, R., M.M. Ranjbar, H.A. Moghadam and S.Y. Mousavi, 2011. Mechanical properties and durability assessment of rice huskash concrete, Biosystems Engineering, 110(2): 144-152.
35. Gastaldini, A.L.G., G.C. Isaia, A.P. Saciloto, F. Missau and T.F. Hoppe, 2010. Influence of curing time on the chloride penetration resistance of concrete containing rice husk ash: A technical and economical feasibility study. Cement and Concrete Composites 32(10): 783-793.
36 Chindaprasirt, P., S. Rukzon and V. Sirivivatnanon, 2008. Resistance to Chloride Penetration of Blended Portland Cement Mortar Containing Palm Oil FuelAsh, Rice Hush Ash and Fly Ash. Construction and Building Materials, 22(5): 932-938.
37 Mehta, P.K., 1977. Properties of Blended Cements Made from Rice Husk Ash.American Concrete Institute, 74(9): 440-442.
38. De Sensale, G.R., 2010. Effect of rice husk ash on durability of cementitious materials. Cement and Concrete Composites, 32(9): 718-725.
39. Chatveera, B. and P. Lertwattanaruk, 2011. Durability of conventional concretes containing black rice husk ash. Journal of Environmental Management, 92(1): 59-66.
40. Memon, S.A., M.A. Shaikh and H. Akbar, 2011. Utilization of Rice Husk Ash as viscosity modifying agent in Self Compacting Concrete. Construction and Building Materials, 25(2): 1044-1048.
41, Shukla, A., C. K. Singh and A.K. Sharma, 2011. Study of the Properties of Concrete by Partial Replacement of OrdinaryPortland Cement by Rice Husk Ash. International Journal of Earth Sciences and Engineering, 4(6): 965-968.
42. Jaya, R.P., B.H.A. Bakar, M.A.M. Johari and M.H.W. Ibrahim, 2011. Strength and permeability properties ofconcrete containing rice husk ash with different grinding time. Central European Journal of Engineering, 1(1): 103-112.

43. Raman, S.N., T. Ngo, P. Mendis and H.B. Mahmud, 2011. High-strength rice husk ash concrete incorporating quarry dust as a partial substitute for sand. Construction and Building Materials 25(7): 3123-3130.
44. Safiuddin, M., J.S. West and K.A. Soudki, 2011. Flowing ability of the mortars formulated from self-compacting concretes incorporating rice husk ash. Construction and Building Materials, 25(2): 973-978.
45. Zerbino, R., G. Giaccio and G.C. Isaia, 2011. Concrete incorporating rice husk ash without processing. Construction and Building Materials, 25(1): 371-378.
46. Habeeb, G.A.and H.B. Mahmud, 2010. Study on Properties of Rice Husk Ash and Its Use as Cement Replacement Material. Materials Research, 13(2): 185-190.
47. De Souza Rodrigues, C., K. Ghavami and P. Stroeven, 2010. Rice Husk Ash as Supplementary Raw Material for the Production of Cellulose Cement Compositeswith Improved Performance. Waste Biomass Valor, 1(2): 241-249.
48. Muthadhi, A. and S. Kothandaraman, 2010. Optimum production conditions for reactive rice husk ash. Materials and Structures, 43(9): 1303-1315.
49. Habeeb, G.A. and M.M. Fayyadh, 2009. Rice Husk Ash Concrete: the Effect of RHA Average Particle Size on Mechanical Properties and Drying Shrinkage. Australian Journal Basic and Applied Sciences, 3(3): 1616-1622.
50. Gastaldini, A.L.G., G.C. Isaia, A.P. Saciloto, F. Missau and T.F. Hoppe, 2009. Influence of Fineness of Rice Husk Ash and Additives on the Properties of Lightweight Aggregate, Fuel, 88(1): 158-162.
51. Dakroury, A.E. and M.S. Gasser, 2008. Rice Husk Ash (RHA) as Cement Admixture for Immobilization of Liquid Radioactive Waste at Different Temperatures. Journal of Nuclear Materials, 381(3): 271-277.
52. De Sensale, G.R., Antonio B. Ribeiro and A. Gonçalves, 2008. Effects of RHA on autogenous shrinkage of Portland cement pastes. Cement and Concrete Composites, 30(10): 892-897.
53. Chindaprasirt, P., S. Homwuttiwong and C. Jaturapitakkul, 2007. Strength and water permeability of concrete containing palm oil fuel ash and rice husk–bark ash. Construction and Building Materials, 21(7): 1492-1499
54. Giaccio, G., G.R. de Sensale and R. Zerbino, 2007. Failure mechanism of normal and high-strength concrete with rice-husk ash. Cement and Concrete Composites, 29(7): 566-574.
55. Bui, D.D., J. Hu and P. Stroeven, 2005. Particle Size Effect on the Strength of Rice Husk Ash Blended Gap-Graded Portland Cement Concrete. Cement and Concrete Composites, 27(3): 357-366.
56. De Sensale, G.R., 2006. Strength development of Concrete with Rice-Husk Ash. Cement and Concrete Composites, 28(2): 158-160.
57. Nair, D.G., K.S. Jagadish and F. Alex, 2006. Reactive Pozzolan as from Rice Husk Ash: An Alternative to Cement for Rural Housing. Cement and Concrete Research, 36(6): 1062-1071.
58. Givi, N.A., S.A. Rashid, F.N.A. Aziz and S.M.A. Mohd, 2010. Assessment of the Effects of Rice Husk Ash Particle Size on Strength, Water Permeability and Workability of Binary Blended Concrete. Construction and Building Materials, 24(11): 2145-2150.
59. Horsakulthai, V., S. Phiuvanna and W. Kaenbud, 2011. Investigation on the corrosion resistance of bagasse-rice husk-wood ash blended cement concrete by impressed voltage, Construction and Building Materials, 25(1): 54-60.
60. Chindaprasirta, P., P. Kanchandaa, A. Sathonsaowaphaka and H.T. Cao, 2007. Sulfate Resistance of Blended Cements Containing Fly Ashand Rice Husk Ash. Construction and BuildingMaterials, 21(6): 1356-1361.
61. Ramezanianpour, A.A., M. Mahdi khani and G.H. Ahmadibeni, 2009. The Effect of Rice Husk Ash on Mechanical Properties and Durability of Sustainable Concretes. International Journal of Civil Engineerng, 7(2): 83-91.
62. Babaiefar, S., 2007. The durability assessment of concrete made withrice husk ash (RHA) in sulfate environment. M.Sc. thesis, Rasht, Iran: University of Guilan.
63. Santhanam, M., M.D. Cohen and J. Olek, 2002. Mechanism of sulfate attack: a freshlook-part 1: summary of experimental results. Cement Concrete Research, 32: 915-21.
64. Santhanam, M., M.D. Cohen and J. Olek, 2003. Mechanism of sulfate attack: a fresh look-part 2: proposed mechanisms. Cement Concrete Research, 33: 341-6.
65. Da Silva, F.G., Jefferson B.L. Liborio and P. Helene, 2008. Improvement of physical and chemical properties of concrete with brazilian silica rice husk (SRH). RevistaIngeniería de Construcción, 23(1): 18-25.

66. Gastaldini, A.L.G., G.C Isaia, N.S. Gomes and J.E.K. Sperb, 2007. Chloride penetration and carbonation in concrete with rice husk ash and chemical activators. Cement and Concrete Composites, 29(3): 176-180.
67. Papadakis, V.G., C.G. Vayenas and M.N. Fardis, 1991. Fundamental modeling and experimental investigation of concrete carbonation. ACI Materials Journal, 88(5): 363-373.
68. Rukzon, S., P. Chindaprasirt and R. Mahachai, 2009. Effect of grinding on chemical and physical properties of rice husk ash.International Journal of Minerals, Metallurgy and Materials, 16(2): 242-247.
69. Habeeb, G.A. and M.M. Fayyadh., 2009. Rice Husk Ash Concrete: the Effect of RHA Average Particle Size on Mechanical Properties and Drying Shrinkage. Australian Journal of Basic and Applied Sciences, 3(3): 1616-1622.
70. Mahmud, H.B, M.F.A. Malik, R.A. Kahar, M.F.M. Zain and S.N. Raman, 2009. Mechanical properties and Durability of Normal and Water Reduced High Strength 60 grade concrete Containing Rice Husk Ash. Journal of Advanced Concrete Technology, 7(1): 21-30.
71. Wu, D.S. and Y.N. Peng, 2003. The macro and micro properties of cement pastes with silica rich materials cured by wet mixed steaming injection. Cement and Concrete Research, 33: 1331-1345.
72. Zhang, M.H. and V.M. Malhotra, 1996. High-performance concrete incorporating rice husk ash as asupplementary cementing material. ACI Materials Journal, 93(6): 629-636.