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Study of various properties of self consolidated concrete using rice husk ash

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ABSTRACT

This study develops the compressive strength, water permeability and workability of concrete by partial replacement of cement with agro-waste rice husk ash. Two types of rice husk ash with average particle size of 5 micron (ultra fine particles) and 95 micron and with four different contents of 5%, 10%, 15% and 20% by weight were used. Replacement of cement up to maximum of 15% and 20% respectively by rice husk ash, produces concrete with improved strength. However, the ultimate strength of concrete was gained at 10% of cement replacement by ultra fine rice husk ash particles. Also the percentage, velocity and coefficient of water absorption significantly decreased with 10% cement replacement by ultra fine rice husk ash. Moreover, the workability of fresh concrete was remarkably improved by increasing the content of rice husk ash especially in the case of coarser size. It is concluded that partial replacement of cement with rice husk ash improves the compressive strength and workability of concrete and decreases its water permeability. In addition, decrease in rice husk ash average particle size provides a positive effect on the compressive strength and water permeability of hardened concrete but indicates adverse effect on the workability of fresh concrete.

Keywords: RHA, CTM, Concrete.

1. INTRODUCTION

Nowadays, there is an increasing interest in the utilization of waste materials. In the case of construction industry there has been a growing trend towards the development and use of waste as supplementary cementitious materials. The common pozzolanic agents from industry and agriculture by-products such as fly ash and rice husk ash (RHA) are becoming (Al-Khala et. al, 1984) active areas of research since not only do their use leads to diversified product quality of the blended cement concrete, but also leads to reduction in cost and negative environmental effects. Rice husk is one of the main agricultural residues obtained from the outer covering of rice grains during the milling process (Figure 1). It constitutes 20% of the 500 million tons of paddy produced in the world. The rice husk ash had no useful application and had usually been dumped into water streams and caused pollution and contamination of springs until it was known to be a useful mineral admixture for concrete. Generally, mineral admixtures have a favorable influence on the strength and durability of concrete.

In the case of RHA, the compressive strength of blended concrete structures has been shown to be enhanced and water permeability to be decreased chemically and physically. In addition of high strength and performance embedding high contents of rice husk ash resulted in high electrical resistivity. The reactivity of amor-phous silica is directly proportional to the specific surface area of ash (Bui et al, 1995). The chemical reaction of amorphous silica with Ca^{2+}, OH- ions and calcium hydroxide during the cement hydration forms more calcium silicate hydrate gel (C–S–H) that is known to contribute to the improvement in the strength and durability properties of concrete

The effects of RHA on physical properties of concrete are linked to its average particle size. Fine particles operate as refinement on the pore structure, act as nucleation point for hydration products, and restrict development of the unfavourable crystals generated in the hydration process. Also the increment in the compressive strength and decrease in the water permeability of concretes re-lated to physical effects can be justified by the filler effect of fine particles of RHA in concrete matrix. Moreover, RHA could affect on physical properties of fresh con-crete (concrete before hardening) by improving the workability (at the same water-binder ratio) which is necessary for mixing and forming. Workability is mainly dependent on water to cement ratio. However, too much mixing water is probably the most important cause for many problems such as strength reduction that may be encountered with concrete mixtures. It has been shown that rheological behavior of concrete can improve at the same water to binder ratio with mineral admixtures and their blending. Several studies have been published on the performance of RHA blended concrete; however, only limited information is available on the influence of RHA particle size on blended con-crete characteristics. This study investigates the effects of partial replacement of cement with different percentages and particle sizes of RHA on the compressive strength (Della et al. 2005), water permeability and workability of concrete to develop a structure with most favorable properties.

2. MATERIALS AND MIXTURES

2.1. Materials and Mixtures

2.1.1. Cement

Ordinary Portland cement of 43 grade from single lot was used in this investigation. It was fresh and without lumps. All tests on cement were conducted, as per procedure laid down in code IS 12269-1987. The chemical and physical properties of the cement are shown in Table 1.

2.1.2. Rice husk ash (RHA)

The RHA was produced by controlled incineration by a local supplier. The ash was sieved and the particles passing the finesses of 150 μm and 33 μm were grinded using Los Angeles mill for 30 and 180 min respectively which yielded two different RHA (Naji Givi et al. 2010) samples having average particle sizes of 95 μm and 5 μm. The two produced samples were used in the experiment. The chemical composition and physical properties of the two RHA types are given in Table 1. Also the particle size distribution curves of OPC and both sizes of RHA are shown in Figure 2.

2.1.3. Aggregates

Locally available natural sand with particles smaller than 0.5 mm, fineness modulus of 2.25 and specific gravity of 2.58 g/cm^3 was used as fine aggregate. Crushed basalt stored in the laboratory with maximum size of 15 mm and specific gravity of 2.96 g/cm^3 was used as coarse aggregate.

2.1.4. Mixture proportioning

A total of three series of mixtures were prepared in the laboratory trials. The control mixtures were made of natural aggregates, cement and water. The mixtures were prepared by replacing 5%, 10%, 15% and 20% of cement with RHA.

Table 1

Chemical and physical properties of Portland cement and RHA (wt.%)

Chemical properties									
Material	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Loss on ignition
Cement	21.89	5.3	3.34	53.27	6.45	3.67	0.18	0.98	3.21
RHA [a]	87.86	0.68	0.93	1.30	0.35	–	0.12	2.37	–

Physical properties	Specific gravity (g/cm^3)	Specific surface (BET) (m^2/g)	Specific surface (Blain) (m^2/kg)
Cement	1.7	–	314
RHA M series [b]	–	24	–
RHA U series [c]	–	36.47	–

[a] Rice husk ash.

[b] M series: RHA-blended concrete with average particle size of 95 lm. [c] U series:

Table 2

Mixture proportion of RHA-blended concretes

Sample designation	RHA (%)	Quantities (kg/m^3)	
		Cement	RHA
C0 (control)	0	450	0
M1 [a], U1 [b]	5	428	22
M2, U2	10	405	45
M3, U3	15	383	67.5
M4, U4	20	360	90

M series: RHA-blended concrete with average particle size of 95 lm.

U series: ultra fine RHA-blended concrete.

Table 3

Compressive strength of RHA blended cement mortars

Sample designation	RHA (%)	Compressive strength (MPa)		
		7 days	28 days	90 days
C0 (control)	0	27.3	36.8	42.3
M1 [a]	5	25.7	38.7	43.5
M2	10	25.1	40.6	46.1
M3	15	23.7	37.9	42.7
M4	20	21.5	36.7	41.3

Water to binder [cement + RHA] ratio of 0.40.

[a] M series: RHA-blended concrete with average particle size of 95 lm.

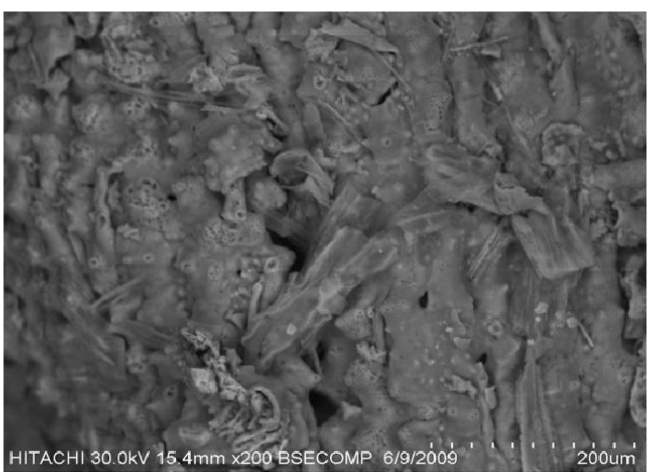

Figure 1

SEM image of as-received rice husk ash

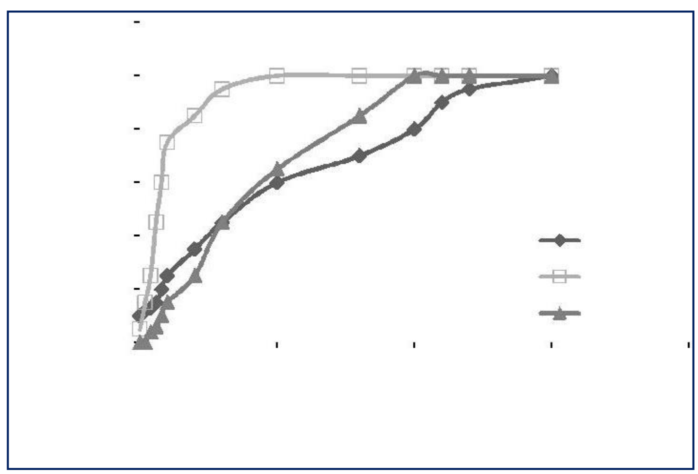

Figure 2

The particle size distribution curves of OPC and RHA

The water to binder ratio for all mixtures was set at 0.40. The aggregates for the mixtures consisted of a combination of crushed basalt and fine sand, with 30 weight percent of sand. The binder content of all mixtures was 450 kg/m^3. The proportions of the mixtures are presented in Table 2.

2.2. Preparation of Test Specimens

M and U series mixtures were prepared by mixing the coarse aggregates, fine aggregates and powder materials (cement and RHA) in a laboratory concrete drum mixer. The powder material in the C0 series mixtures was only cement. They were mixed in dry condition for 2 min followed by another 3 min after adding the water. Slumps of the fresh concrete were determined immediately to evaluate the work-ability following the mixing procedure. Cubes of 150 mm edge were cast and compacted in two layers on a vibrating table, where each layer was vibrated for 10 s. The moulds were covered with gunny bags and moistened for 24 h. Then the specimens were demoulded and cured in water at a temperature of 20 ^{0}C prior to test days. The compressive strength and water absorption test of the concrete samples were determined at 7, 28 and 90 days. The reported results are the average of three trials.

2.3. Compressive Strength of RHA-Blended Concrete

Compressive strength of RHA-blended concrete cubes was determined in accordance to the CTM after 7, 28 and 90 days of moisture curing.

2.4. Velocity of Water Absorption

Velocity of water absorption is a measure of the capillary forces exerted by the pore structure causing fluids to be drawn into the body of the material. In this experiment, the speed of water absorption by concrete cubes were considered by measuring the increase in the mass of samples due to water absorption at certain times when only one surface of the specimen is exposed to water. Concrete samples were dried in an oven at 50 ^{0}C for 3 days and then cooled in a sealed container at 23 ^{0}C for 15 days after 7, 28 and 90 days of moist curing. The sides of the concrete samples were covered with epoxy resin in order to allow the flow of water in one direction. The end of the samples were sealed with tightly attached plastic sheet and protected in position by an elastic band. The initial mass of the samples were taken after which they were kept partly immersed to a depth of 5 mm in water. The readings were started with the initial mass of the sample at selected times after first contact with water (typically 1, 5, 10, 20, 30, 60, 110 and 120 min), the samples were removed, excess water was blotted off using paper towel and then weighed. Then they were replaced again in water for the chosen time period. The gain in mass (Δm, kg/s$^{1/2}$) at time t (s), exposed area of the specimen (a, m^2), and density of water (d, kg/m^3), were used to obtain the rate of water absorption (I, m/s$^{1/2}$) as per the equation:

$$I=\Delta m/(aXd)$$

2.5. Coefficient of Water Absorption

Coefficient of water absorption is considered as a measure of permeability of water. This was measured by determining the rate of water uptake by dry concrete in a period of 1 h. The concrete samples were dried at 110 ^{0}C in an oven for one week until they reached to constant weight and then were cooled in a sealed container for 1 day (Zivica V et. al, 2009). The sides of the samples were covered with epoxy resin, and were placed partly immersed in water to a depth of 5 mm at one end, and at the other end a tightly attached plastic was secured in position by an elastic band. The amount of water absorbed during the first 60 min was calculated for RHA-blended concrete samples after 7, 28 and 90 days of moisture curing using the formula:

$$Ka= (Q/A)^2/t¼$$

where Ka is the coefficient of water absorption (m^2/s), Q is the quantity of water absorbed (m^3) by the dried samples in 3600 s and A is the surface area (m^2) of concrete samples through which water penetrates.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1. Compressive Strength

3.1.1. M series mixtures

The compressive strength results of C0 and M series are shown in Table 3. Comparison of the results from the 28 and 90 days samples shows that the compressive strength increases by replacing the cement with RHA up to 10% replacement (M2) and then it decreases, although specimens with 15% replacement (M3) have still higher compressive strength than those of the control concrete (C0). Table 3 also shows that replacing the cement by 20% RHA de-creases the compressive strength to a value which is lower than that of control concrete. This may be due to the fact that the quantity of RHA presents in the mix is higher than the amount required to combine with the liberated lime during the hydration process thus leading to excess silica leaching out causing a deficiency in strength as it replaces part of the cementitious material but does not contribute to strength. On the other hand, for early age concrete, the compressive strength is declined for the samples at 7 days in the presence of RHA compared to the control concrete. This decline in early age strength is as a result of low pozzolanic activity of RHA due to its coarser particles. Additionally, the reduction in volume of hydration products due to less favorable hydration rate is expected to result in a decrease in the early age strengths.

Table 4

Compressive strength of concrete blended with ultra fine RHA

Mix designation	RHA (%)Compressive strength (MPa)		
	7 days	28 days	90 days
U1 [a]	527.4	39.9	45.8
U2	1028.3	43.8	51.2
U3	1525.9	39.1	44.4
U4	2024.6	38.3	42.8

Water to binder [cement + RHA] ratio of 0.40. [a] U series: ultra fine RHA-blended concrete.

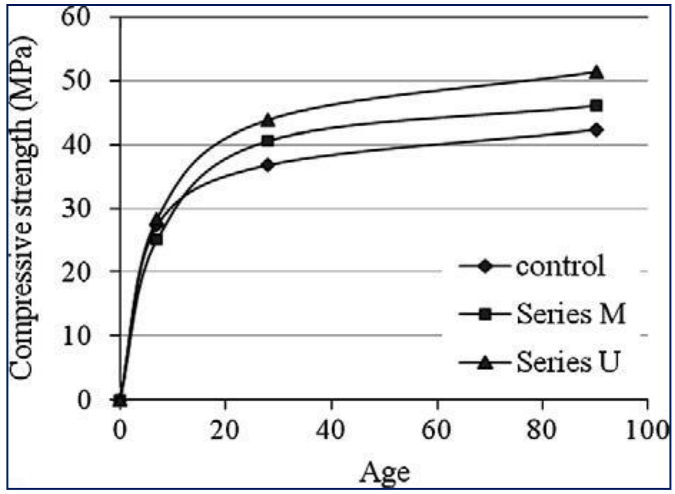

Figure 3

Compressive strength development for M[a] and U[b] series at 10% level of cement replacement by RHA in comparison to control sample at the first 90 days. M series: RHA-blended concrete with average particle size of 95 lm. U series: ultra fine RHA-blended concrete

3.1.2. U series mixtures

The compressive strength results of U series samples are given in Table 4. As expected, concrete samples made with the ultra fine RHA particles showed considerably higher strength than those made with the coarser RHA for all cement replacement ratios. The compressive strengths of the U series mixtures are higher than that of the control concrete at all ages apart from the U3 and U4 series at 7 days which are slightly lower than C0 series at the same age. The compressive strengths development with age for M and U series at 10% (optimal) level of cement replacement by RHA in comparison to C0 series are shown in Figure 3. The highest enhancement in compressive strength of the U series was obtained similar to M series for RHA content of 10% at 90 days age. The compressive strength of U4 at 90 days age be-comes approximately equivalent with C0 at the same age. These favorable results of ultra fine RHA-blended concrete are due to the rapid consuming of $Ca(OH)_2$ which was formed during hydration of Portland cement at early ages that is related to the high pozzolanic reactivity of ultra fine RHA. As a consequence, the hydration of cement is accelerated and larger volumes of reaction products are formed. Also the fine RHA particles recover the particle packing density of the blended cement, directing to a reduced volume of larger pores in the cement paste. The results show that the compressive strength of U2 series mixtures in comparison by M2 series mixtures at 7, 28 and 90 days were improved by 12%, 7% and 11%, respectively.

3.2. Percentage of Water Absorption

The results of saturated water absorption at different ages of moist curing are shown in Table 5. The percentage of water absorption of concrete samples immersed in water decreases with increasing the age of moist curing from 7 to 90 days for all three series during the hardening process of the concrete. The reduction of water absorption was found at the 7 days curing for U series compared to other series but at the 7 and 28 days curing the percentage of water absorption increased in M series compared to C0 series. This may be due to the nature of RHA particles which is hygroscopic. The increase in water absorption which is related to the increase in the amount of RHA can be resulted from the reduced amount of OPC. These results were achieved because of fewer hydration products when the pozzolanic reaction is small at the early ages for M series reverse of the U series. On the other hand, the percentage of water absorption related to the porosity of the hardened concrete which is engaged by water in saturated state was more in M series compared to other series at the early ages. But by increasing the age of curing to 90 days, the percentage of water absorption values decreases significantly with the in-crease in RHA content up to 10% for both M and U series. Even at 20% RHA in both M and U series, the values were lower compared to C0 series.

Table 5

Results of permeability related properties of concrete incorporating rice husk ash

Mix designation	RHA (%)	P.W.A [a] (%) 7 days	28 days	90 days	V.W.A [b] _ 10^{-6} ($m/s^{1/2}$) 7 days	28 days	90 days	C.W.A [c] _ 10^{-10} (m^2/s) 7 days	28 days	90 days
C0	0	7.47	5.60	4.80	13.22	12.34	10.14	9.02	2.86	1.35
M1 [d]	5	7.80	5.94	4.32	13.43	12.76	9.89	9.23	2.98	1.25
M2	10	7.49	5.78	4.15	13.29	12.39	9.03	9.20	2.96	1.13
M3	15	7.86	6.05	4.59	13.48	12.81	9.92	9.37	3.10	1.25
M4	20	7.92	6.13	4.68	13.53	13.03	10.11	10.10	3.24	1.32
U1 [e]	5	6.90	5.22	3.98	12.64	11.38	6.89	8.56	2.47	1.03
U2	10	6.67	5.11	3.51	10.72	8.64	5.14	7.30	1.97	0.89
U3	15	6.94	5.28	4.01	12.60	11.70	8.32	8.67	2.55	1.12
U4	20	7.10	5.41	4.14	12.86	11.73	9.16	8.83	2.57	1.20

Percentage of water absorption.

Velocity of water absorption.

Coefficient of water absorption.

M series: rice husk ash blended concrete with average particle size of 95 lm.

U series: ultra fine RHA-blended concrete.

3.3. Velocity of Water Absorption

The velocity of water absorption of all three series is shown in Table 5. At 7 days of curing, there was a progressive reduction in the velocity of water absorption in U series. With increase of RHA (Ganesan et al. 2008) content up to 15% and 20% of RHA blending an increase in the velocity of water absorption was observed but the values are still lower than the control concrete. Also the increase in velocity of water absorption was observed for M series at 7 and 28 days. With progressing in the curing time until 90 days the velocity of water absorption for both series at all replacement contents are quite lower than series C0. It is well known that mineral admixtures with fine particles can improve the filler effect and also the high pozzolanic action of fine particles increases substantially the quantity of C–S–H gel. If this phenomenon joins with low water cement ratio, it can improve the microstructure in the interfacial transition zones and thus the value of C–S–H gel, then the water permeability can be considerably increased.

3.4. Workability

Basically, the bigger the measured height of slump, the better the workability will be, indicating that the concrete flows easily but at the same time is free from segregation. Usually typical concrete mixtures contain too much mixing water because of two reasons: Firstly, the water demand and workability are significantly influenced by particle size distribution, particle packing effect, and voids present in the solid system. Typical concrete mixtures do not have an optimum particle size distribution, and this accounts for the undesirably high water requirement to achieve certain workability. Secondly, to plasticize a cement paste for achieving an acceptable consistency, much larger amounts of water than necessary for the hydration of cement have to be used because Portland cement particles, due to the presence of electric charge on the surface, tend to form flocs that trap volumes of the mixing water. The results show that the water to binder ratio can be decreased in the presence of RHA (Aiqin et al., 1999) particles regardless of its particle size to achieve certain workability. Therefore, the cement particles are effectively dispersed and could trap large amounts of water that results in the reduction of water requirement of the system to achieve an acceptable consistency. The particle packing effect is also associated with the reduced water demand. Regarding the particle size range of the Portland cement (1– 45 μm) the particle size of RHA (Naji Givi et al. 2010) is very important to serve as excellent filler for the void space within the cement particles. The results of the current study indicate that the workability of M series was increased more than U series at the same contents. This phenomenon might occur because of high water requirement due to increased specific surface of RHA particles.

4. CONCLUSION

The results show that the RHA-blended concrete had higher compressive strength at 90 days in comparison with that of the concrete without RHA, although at 7 and 28 days different behaviors were ob-served between the concretes with the two RHA considered. It is found that the cement could be advantageously replaced by RHA up to maximum limit of 15% and 20% with average particle sizes of 95 and 5 μm, respectively. Although, the optimal level of RHA con-tent for both average particle sizes were achieved with 10% replacement. Test results show a significant reduction in percentage of water absorption, velocity of water absorption and also coefficient of water absorption at all ages with ultra fine RHA particles. However, RHA-blended concrete with average particle size of 95 μm has shown a reduction in water permeability only after 90 days moisture curing. Partial replacement of cement by RHA improved workability of fresh concrete for both used average particle sizes. However, the RHA with average particle size of 95 lm gave rise to higher slump values for comparable cases. Test results of this study show that using RHA as partial cement replacement contributes to reduction of the amount of cement required for making concrete up to 20% of weight by agro waste material and with more satisfaction requirements compared to plain cement concrete. Ultimately it was found that U2 could be considered as an optimum formulation because of its high value of compressive strength, less water permeability and acceptable workability.

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