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Rice Husk Ash Concrete: the Effect of RHA Average Particle Size on Mechanical Properties and Drying Shrinkage

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Abstract: This paper reports an experimental investigation on the influence of Rice Husk Ash (RHA) Average Particle Size (APS) on the mechanical properties and drying shrinkage of the produced RHA blended concrete. Locally produced RHA with three deferent APS (i.e., 31.3, 18.3, and 11.5 µm, respectively) were used to replace cement by 20 % of its weight. Mixture proportioning was performed to produce high workability RHA mixture (200-240 mm slump) with target strength of 40 MPa. Incorporation of RHA in concrete resulted in increased water demand, for the mechanical properties, inclusion of RHA provided similar or enhanced mechanical properties when compared to the control Ordinary Portland Cement (OPC) mixture, with finer RHA giving better improvement. Fine RHA exhibited the highest shrinkage value due to the effect of microfine particles which increases its shrinkage values considerably.

Key words: fineness; pozzolan; workability; strength; XRD; shrinkage

INTRODUCTION

From 1880 to 1996, the world's annual consumption of Portland cement rose from 2 million tons to 1.3 billion tons. This was associated with major environmental cost include: a) cement manufacturing is the third largest CO_2 producer and for over 50% of all industrial CO_2 emissions (for every 1ton of cement produced, 1.25 ton of CO_2 is released in the air); b) 1.6 ton of natural resources is consumed to produce 1 ton of cement (Muga, H., K. Betz, 2005). This calls for the use of sustainable binders. One of the most promising materials is the rice husk ash (RHA).

Rice husk is an agricultural residue from the rice milling process. According to the United Nations FAO (2008), the annual world rice production for 2007 was estimated by 649.7 million tons, the Husk constitute approximately 20% of it. The chemical composition of Rice Husk is found to vary from sample to another due to the differences in the type of paddy, crop year, climate and geographical conditions (Chandrasekhar, S., S.K.G. Pramada, 2003). Burning the husk under controlled temperature below 800° can produce ash with silica mainly in amorphous form (Chandrasekhar, S., S.K.G. Pramada, 2003; Zhang, M.H., V.M. Malhotra, 1996).

A state-of-the-art report on rice husk ash (RHA) was published by Mehta 1992, and contains a review of physical and chemical properties of RHA, the effect of incineration conditions on the Pozzolanic characteristics of the ash, and a summary of the research findings from several countries on the use of RHA as a supplementary cementing Pozzolanic material. Pozzolan- a siliceous or alumino-siliceous material that in itself possesses little or no Cementitious value but that in finely divided form and in the presence of moisture will chemically react with alkali and alkaline earth hydroxides at ordinary temperatures to form or assist in forming compounds possessing cementitious properties (ASTM, 1995). So far, according to the author's literature, RHA has not been utilized yet in the construction industry, except for some repairing works in the US where it was used in a dry-mix shotcrete to repair the Bowman Dam in northern California's Sierra Nevada Mountains, with positive results (Talend, D., 1997). The reason for not utilising this material may be probably due to lack of understanding of the RHA blended concrete characteristics. Many researchers have already published on the properties of the blended RHA concrete such as strength and durability. However, only few researches were found on the effect of RHA Average Particle Size (APS) on the properties of concrete. The objective of this paper is to investigate the effect of RHA APS on the behaviour of the blended RHA concrete.

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MATERIALS AND METHODS

The work presented in this paper reports an investigation on the behaviour of concrete produced from blending ASTM Type I cement with various APS of RHA. The physical and chemical properties of RHA and OPC were first investigated. Mixture proportioning was performed to produce high workability concrete (200-240 mm slump) with target strength of 40 MPa for the control mixture. The effect of RHA APS on concrete properties was studied by means of the fresh properties of concrete and the mechanical properties. i.e., compressive strength, tensile splitting strength, modulus of rupture, and static modulus of elasticity. Furthermore, the drying shrinkage was studied as the time dependent property.

2.1 Materials:
2.1.1 Cement:

An ASTM type I cement was used; its physical and chemical properties are given in Table 1. The Blaine surface area test was conducted according to ASTM C 204-94a and it is shown in Table 2.

Table 1: physical and chemical properties of RHA and OPC

Material	Specific Gravity	Chemical analysis (%)							
		SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O_3	K_2O	LOI
OPC	2.94	20.99	6.19	3.86	65.96	0.22	0.17	0.6	1.73
RHA	2.11	88.32	0.46	0.67	0.67	0.44	0.12	2.91	5.81

Table 2: The average particle size and surface area of RHA and OPC

Material	OPC	RHAF1	RHAF2	RHAF3
Avg. Particle size (µm)	22.1	31.3	18.3	11.5
Bet's Nitrogen Adsorption (m^2/g)	-	27.4	29.1	30.4
Blaine's surface area(m^2/kg)	351.4	-	-	-

RHAF1: 180 min. grinding, RHAF2: 270 min grinding and RHAF3: 360 min. grinding

2.1.2 Rice Husk Ash:

The Rice Husk Ash Used in this work was made in the laboratory by burning the husk using a Ferro-cement furnace (Mahmud, H.B., 1995), with incinerating temperature not acceding 700˚ c. The ash was grinded using Los Angeles mill for 180, 270 and 360 minutes, The XRD analysis were performed to determine the silica form of the produced RHA Powder samples, they were scanned by an X-ray diffractometer using *CuKα* radiation at 40 kV/20mA, CPS=1k, width 2.5, speed 2˚/min and scanning from 2θ = 3-70˚. The graph indicates that the ash was mainly in amorphous form, see Figure 1. RHA samples were scanned by electron microscope to show the RHA's multilayered and microporous surface, see figure 2.

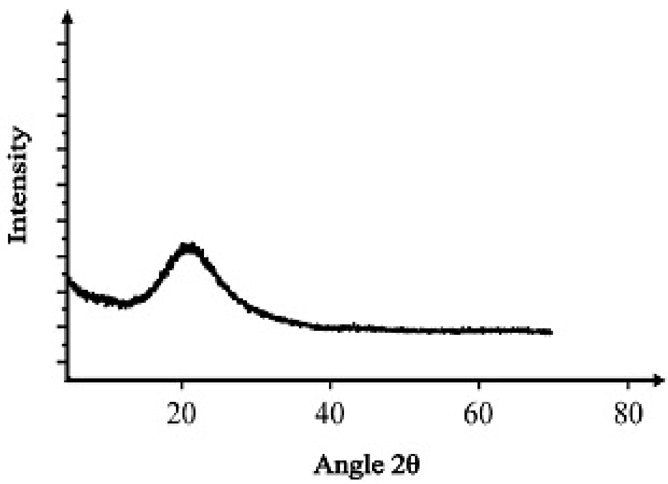

Fig. 1: The X-Ray spectrum

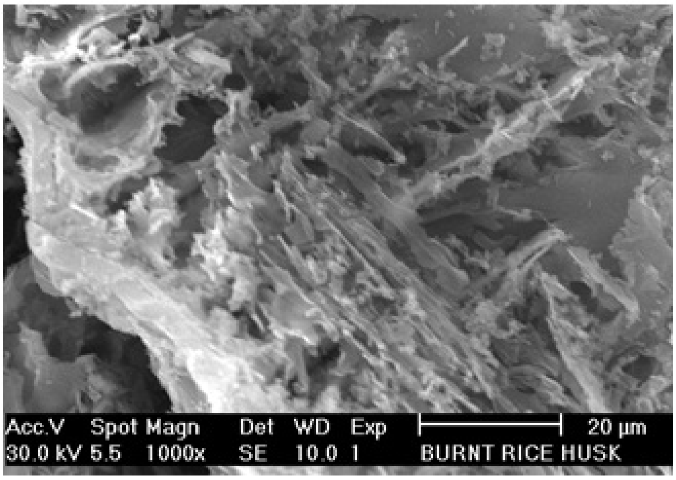

Fig. 2: SEM for RHA particle

The physical and chemical properties of RHA are shown in Table 1. The chemical composition of the RHA is determined using the XRF (X-ray fluorescence spectrometry). The particle size analyses were done by using the MasterSizer laser particle analyser with Obscuration 12.3 % and beam length of 2.40 mm. The Nitrogen adsorption test was done to verify the effect of grinding on the specific surface area of RHA, see table 2.

2.1.3 Aggregate:

The Fine aggregate used were mining sand passing from 4.75 mm sieve with specific gravity of 2.61 and absorption 0.76 %. The coarse aggregate were crushed granite with size of 19-4.75 mm with specific gravity of 2.65 and water absorption 0.5 %.

2.1.4 Chemical Admixture:

To maintain high workability of the concrete mixes of 200 – 240 mm slump, an ASTM C494 type-A high range water-reducing admixture was used. The R1000 superplasticizer was a dark brown, water-soluble, chloride free sulphonated naphthalene formaldehyde, having 40 % solid content with specific gravity of 1.2.

2.2 Mixture Proportioning:

The mixture proportioning was done according to the current British mix design method (Department Of Environment DOE) (Neville, A.M., 2005). The target mean strength was 40 MPa for the OPC control mixture, the total binder content was 391 kg/m^3, fine to coarse aggregate ratio of 75.4%, the water to binder ratio was kept constant as 0.53, the Superplasticizer content was varied to maintain a slump of (200-240 mm) for all mixtures. The total mixing time was 5 minutes, the samples were then casted and left for 24 hrs before demoulding They were then placed in the curing tank until the day of testing. Details of the mix proportion of the concrete mixes are presented in table 3.

Table 3: Concrete Mixture Proportioning

Mix	W/Binder	Cement (kg)	RHA (kg)	Water (ltr)	F Agg. (kg)	C Agg. (kg)
CM	0.53	391	0	207	750	994
20RHA	0.53	313	78	207	750	994

CM: Control mix, 20RHA: 20 % cement replacement RHA mix.

Cement was replaced with 3 grades of RHA (F1, F2 and F3 i.e. 180, 270 and 360 minutes of grinding respectively). The properties of fresh concrete i.e., slump and fresh density were first investigated, then, the effect of RHA APS on compressive strength at the age of 1, 3, 7, 28, 90, 180 days was studied, 100 mm cubes were cast from each mixture. Specimens were kept in the moulds for 24 hours and then placed in water for curing until the day of testing. The other properties investigated were tensile splitting strength, modulus of rupture, and static modulus of elasticity. These tests were conducted at the age 28, 90, 180 days under water curing regime. The drying shrinkage was also investigated at the age of 7, 14, 28, 42, 56, 90, 180 days under two curing regimes, i.e., water curing for initial seven days then samples were left in the air, and second, air drying. The average relative humidity and temperature in the laboratory were 90 % and 30°c, respectively. These curing conditions were selected in order to imitate the climate conditions in tropical regions like Malaysia.

RESULTS AND DISCUSSION

3.1 Effect of RHA APS on Workability and Density:

The fresh properties of all the concrete mixtures are given in Table 4. The slump was in the range of (210-230 mm), bleeding was negligible for the control mixture. For concretes incorporating RHA, no bleeding or segregation was detected. The fresh density was in range of (2253-2347 kg/m^3), the lowest density values were for 20F1 mixture This is due to the low specific gravity of RHA which lead to reduction in the mass per unit volume. The concrete incorporating finer RHA resulted in denser concrete matrix. The SP content had to be increased along with the RHA fineness and percentage, this due to the high specific surface area of RHA which would increase the water demand (Zhang, M.H., V.M. Malhotra, 1996; Ganesan, K., K. Rajagopal, 2008), therefore, to maintain high workability, Sp content rose up to 2.00 % for the 20F3 mixture.

Table 4: Fresh concrete properties

Mix	W/Binder Ratio	RHA content	SP content	Slump mm	Fresh Density	Bleeding
CM	0.53	0%	0.63%	230	2347	Negligible
20F1	0.53	20%	1.83%	220	2253	-
20F2	0.53	20%	1.90%	215	2270	-
20F3	0.53	20%	2.00%	210	2294	-

3.2 Compressive Strength:

The strength development at various ages is given in Table 5. It can be noted that at early ages the strength was comparable, while at the age of 28 days, finer RHA exhibited higher strength than the sample with coarser RHA. this is due to the higher fineness of RHA which may allowed the RHA particles to increase the reaction with $Ca(OH)_2$ to give more calcium silicate hydrate (C-S-H) resulted in higher compressive strength (Ismail, M.S., A.M. Waliuddin, 1996).

Table 5: Strength development for RHA concrete

Mixture	RHA content	Compressive Strength Mpa					
		1 day	3 days	7 days	28 days	90 days	180 days
CM	0%	19.1	26.7	30.2	39.6	44.1	45.7
20F1	20%	17.3	24.5	29.8	40.6	45.2	46.9
20F2	20%	17.8	24.5	30.5	41.0	46.1	48.1
20F3	20%	18.1	25.2	32.1	41.7	47.3	49.8

3.3 Flexural Strength (Modulus of rupture):

The results of flexural strength are shown in table 6. The values were in the range of 4.5-6.1 MPa. results shows that the addition of RHA to concrete exhibited an increase in the flexural strength and the higher strength was for the finer RHA mixture due to the increased pozzolanic reaction and the packing ability of the RHA fine particles (Zhang, M.H., V.M. Malhotra, 1996).

Table 6: Mechanical properties of concrete

Mix	Flexural Strength (MPa) Age (days)			Tensile Splitting (MPa) Age (days)			Static Modulus (Gpa) Age (days)		
	28	90	180	28	90	180	28	90	180
CM	4.5	4.9	5.1	2.6	2.8	2.9	29.6	30.5	31.0
20F1	4.9	5.4	5.5	2.9	3.0	3.2	30.1	30.8	31.4
20F2	5.0	5.4	5.7	3.2	3.3	3.5	30.2	31.4	31.7
20F3	5.2	5.7	6.1	3.2	3.5	3.9	30.5	32.3	32.9

***3.4 Tensile Splitting Strength*:**

The values of tensile splitting strength at various ages are shown in table 6. They were in the range of 2.6-3.9. It can be clearly seen that the tensile properties has been enhanced by adding RHA to the mixture, the use of RHA resulted in significant improvement in flexural strength (De Sensale, G.R., 2006; Sakr, K., 2006). The coarse RHA mixture (20F1) showed the least improvement.

3.5 Static Modulus of Elasticity:

The results of static modulus are shown in Table 6. The values of the static modulus of elasticity were in the range of 29.6 - 32.9 GPa. It can be noted that the addition of RHA to concrete exhibited marginal increase on the elastic properties, the highest value was recorded for (20F3) mixture due to the increased reactivity of the RHA. Concretes incorporating pozzolanic materials usually show comparable values for the elastic modulus compared to the OPC concrete (Zhang, M.H., V.M. Malhotra, 1996; Giaccio, G., G.R. de Sensale, 2007; Sata, V., C. Jaturapitakkul, 2007).

3.6 Drying Shrinkage:

The shrinkage results at various ages with two curing regimes are illustrated in figure 3. The results showed that the RHA average particle size had a significant effect on the drying shrinkage, the 20F3 concrete Mixture exhibited higher shrinkage value than the control. 20F2 concrete was comparable, while the shrinkage for 20F1 was lower compared to the control. The reduction in the RHA particle size increased the pozzolanic activity and contributed to the pore refinement of the RHA concrete paste matrix. Thus, it can be concluded that the addition of microfine particles to concrete would increase the drying shrinkage. Many researchers showed that concretes incorporating pore refinement additives will usually show higher shrinkage and creep values (Mehta, P.K., P.J.M. Monteiro, 2006; Chandra, S., 1997). On the other hand, others showed that using pozzolanic materials as cement replacement will reduce the shrinkage (Zhang, M.H., V.M. Malhotra, 1996; Chindaprasirta, S.H., V. Sirivivatnanon, 2004). These contradictory results about shrinkage are probably due to interpretational differences based on deferent concepts, definitions and measuring techniques (Rizwan, S.A., 2006). And that may also be because the deferent characteristics and degree of reactivity of the pozzolanic materials used.

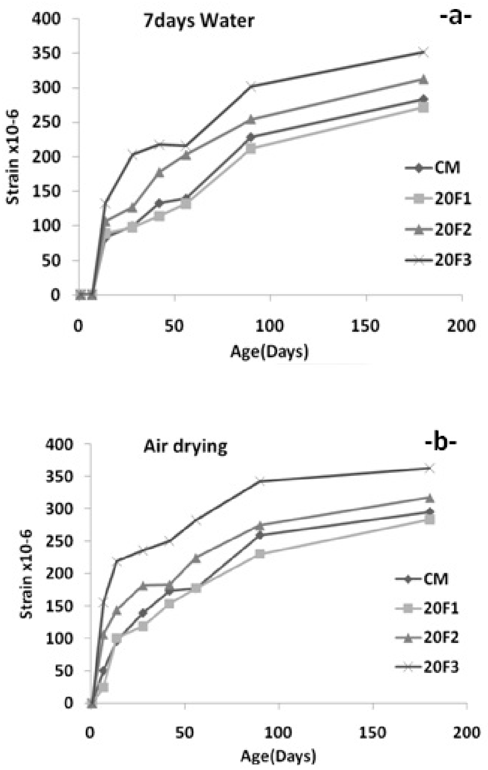

Fig. 3: Shrinkage values at various ages, -a- 7 days initial water curing, -b- air drying.

It can also be noticed that irrespective of the mixture type or the curing regime, the results of shrinkage in this investigation were relatively low compared to the available literature, this would be due to the RH and the temperature values in the laboratory (i.e., ˜90 % RH, ~30°c Temp.). Neville (2005) stated that it is logical to expect that there is an intermediate humidity at which the cement paste will be in dimensional equilibrium and that it would be of 94 percent.

Conclusions:

The RHA Used in this study is efficient as a pozzolanic material; it is rich in amorphous silica (88.32%). The loss on ignition was relatively high (5.81%), this may be due to the amount of unburnt carbon in the ash. Increasing RHA fineness would increase its reactivity.

Due to the high specific surface area of the RHA, the dosage of superplasticizer had to be increased along with RHA fineness to maintain the desired workability.

Increasing RHA fineness would enhance the strength of blended concrete, this due to the increased pozzolanic activity and that RHA will act as a Microfiller in the concrete matrix.

On early age specimens left in air exhibited higher strength than ones left in water. At 28 days onwards, the strength was marginally lower than specimens cured in water. This may be probably due to the high relative humidity and temperature in the lab (~90% and 30°c, respectively).

The mechanical properties in terms of flexural and tensile strength have been significantly improved with the addition of RHA, with the coarse RHA showing the least improvement. On the other hand, the value of Static modulus was comparable with slight increase in the RHA concrete mixtures.

The drying shrinkage was significantly affected by RHA fineness; 20F3 recorded the higher shrinkage value. While 20F1 exhibited lower values than the control, this could be due to the effect of the microfine particles. 7 days of initial water curing has reduced the shrinkage values in all mixes. The high humidity content in the lab resulted in relatively low shrinkage values for all mixtures.

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