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Rice Husk Ash – An Alternative Material to Silica Fume For Production Of 100 MPa Mortar

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ABSTRACT:

This study focuses on the possibility of using rice husk ash (RHA) to produce high performance mortar of 100 MPa. The variables of study include effect of grinding and level of cement replacement with RHA. The fine aggregate used was mining sand instead of silica sand which is frequently used in producing high performance concrete (HPC). The average particle size of the RHA used was 13.50 µm, 20.43 µm and 29.92 µm and level of cement replacement was at 0%, 10 %, 15 % and 20 %. The results show that the use of 10 % RHA with the average particle size of 20.43 µm gave better compressive strength from 3 days onwards compared to control OPC and silica fume and the use of 20% of RHA with the average particle size of 13.50 µm at 28 days gave better compressive strength compared to other concrete.

1 INTRODUCTION

Usage of supplementary cementitious materials (SCM) and superplasticizer (Sp) to produce HPC are necessary (Hover, 1998). Mostly SCM used in HPC are silica fume (SF), fly ash (FA) and ground granulated glass blast-furnace slag (GGBS). SF is the most favorable in HPC due to its very reactive pozzolanic reaction and its ability to improve strength and workability (Duval, 1998). However this kind of cementious material is expensive for developing countries because it must be imported. One alternative to find cheaper cementious material is by utilizing waste from the rice mill, rice husk. Thailand and some states in Malaysia have utilized rice husk as fuel in the rice mills to generate steam for the parboiling process. For states not having utilized it as fuel, rice husk is dumped in open area and burning the residue caused air pollutant. However, by proper burning process with maximum temperature of 700 ^{o}C and grinding the rice husk ash being produced is in amorphous form and categorized as reactive pozzolan (Nair, 2008). Its chemical and physical properties are almost similar to silica fume. There are a lot of studies about utilizing RHA as replacement of SF to achieve either high strength or performance concrete. Chatveera (2011) has reported use of black RHA at 10% cement replacement without reduction of compressive strength of concrete (Chatveera, 2011). Higher proportion of non-reactive silica minerals such as cristobalite and tridymite was found from the ash from open-field burning. However it can still be used in concrete as long as it is ground into very fine particles to develop its pozzolanic activity (de Sensale, 2010). It was also reported that using different average particle sizes of RHA in concrete influence the compressive strength and drying shrinkage (Habeeb, 2009). RHA used either as addition or cement replacement could improve compressive strength of concrete up to 80 MPa (Mahmud, 2005). However, most information of RHA are for normal concrete and high strength concrete of less than 80 MPa and the effects of RHA still remain unclear due to its behavior being related to the chemical and physical properties of RHA. This paper evaluates the effect of level of cement replacement and average particle size of RHA on target compressive strength of mortar of 100 MPa compared to that of OPC and CSF mortar.

2 MATERIALS AND MIX PROPORTIONING

2.1 Materials

The materials used in this research for developing 100 MPa mortar are locally available except for condensed silica fume, which was imported from China. The cementious material used was ordinary Portland cement (OPC), classified as ASTM Type I, and the supplementary cementious material used were rice husk ash (RHA) and condensed silica fume (CSF). Their chemical composition and physical properties are given in Tables 1 and 2, respectively. The chemical composition for different fineness of RHA from the same batch is not much different (Tuan, 2011). The specific surface area (SSA) of cement and CSF was tested by the Blaine test according to ASTM C 204-94a and that of RHA was tested by nitrogen absorption method. The specific gravity (SG) of those materials was determined according to BS 1377: part 2:1990. For the purpose of this research, three different average particle sizes (APS) of RHA were used, labeled as RHA30K, RHA15K and RHA10K, of 13.50 µm, 20.43 µm, and 29.92 µm. For fine aggregate, mining sand was used with specific gravity 2.63, and fineness modulus of 3.0. Particle size distribution of RHA, CSF, cement and mining sand are shown in Fig. 1.

Table 1: Chemical composition of cement and SCM

Oxide	OPC	RHA	CSF
Silicon dioxide (SiO_2)	20.99	90.82	92.06
Aluminium Trioxide (Al_2O_3)	6.19	0.46	0.48
Ferric oxide (Fe_2O_3)	3.86	0.67	2.11
Calcium oxide (CaO)	65.96	0.67	0.40
Magnesium oxide (MgO)	0.20	0.44	0.63
Sodium oxide (Na_2O)	0.17	0.12	0.28
Potassium oxide (K_2O)	0.60	2.91	1.24
Phosphorus oxide (P_2O_5)	0.05	1.00	0.02
Titanium oxide (TiO_2)	0.40	0.02	0.01
Manganese oxide (MnO)	0.06	0.08	0.23
Loss on ignition	1.53	2.81	2.54

Table 2: Physical properties of cement and SCM

Type of material	APS (µm)	SSA (m^2/g)	SG. (g/cm^3)
OPC	22.10	0.351	3.14
RHA10k	29.92	27.4	2.06
RHA15k	20.43	29.1	2.12
RHA30k	13.50	30.4	2.20
CSF	0.50	26.25	2.31

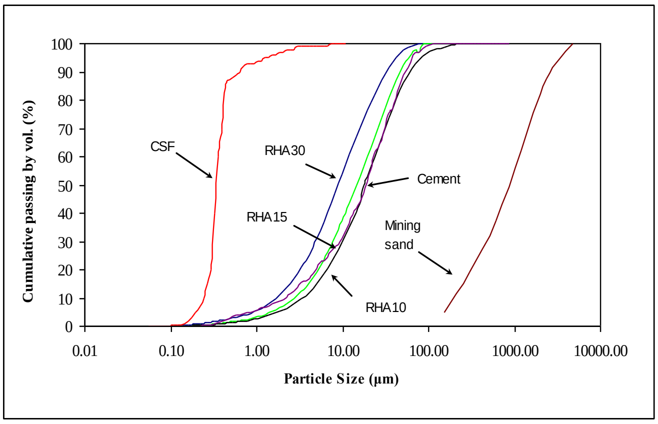


Figure 1: Particle size distribution of RHA, CSF, cement and mining sand

2.2 Mix proportioning

One of the important key factors in HPC mix design is the optimization of the granular mixture. It could be achieved by checking the optimum particle distribution of combination of binder and fine aggregate. Water to binder (W/B) ratio of all the mixtures in this research was adopted to be 0.25. Superplasticizer (Sp) content was adjusted to maintain the mortar mixes with similar slump flow of 290-300 mm. The suggestion of particle distribution model used in this research is the modified Andreassen model (Brouwers, 2005). Figures 2 a, b and c show particle size distributions of RHA concrete incorporating 13.50 µm, 20.43 µm, and 29.92 µm particle size of RHA respectively. By adopting distribution of coefficient equal (q-value) to 0.27 (Zheng, 2009), all the combinations are close to the modified Andreassen curve. Table 3 shows mix proportions of mortar.

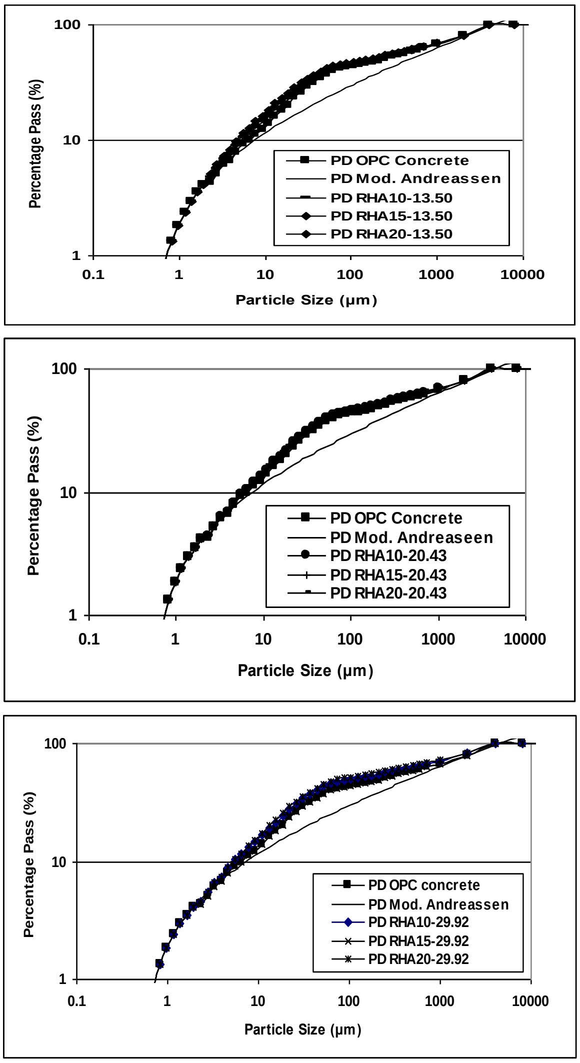


Figure 2: Particle size distribution of mortar incorporating RHA

Table 3: Mix proportion of mortar

Constituent	OPC	CSF10	RHA10	RHA15	RHA20
W/b	0.25	0.25	0.25	0.25	0.25
Sp (%)	0.5	0.95	1.0/1.1/ 1.2	1.1/1.2/1.3	1.7/1.85/2
Water (kg/m3)	137.5	137.5	137.5	137.5	137.5
Cement (kg/m3)	550	495	495	467.5	440
RHA (kg/m3)	0	0	55	82.5	110
CSF (kg/m3)	0	55	0	0	0
Sand (kg/m3)	733.91	711.16	707.35	692.59	671.95

3 MIXING AND TEST

3.1 Mixing Procedure

A 10 L Hobart mixer with 3 step speed was used for mixing all materials. The volume of each batch was 6 L. The mixing procedure is shown in Figure 3. The purpose to put 50 % water first onto the fine aggregate was to make a thin water film on surface of the fine aggregate for coating and make mixing with cement easy. To verify the workability of all mixtures the slum flow test between 290 and 300 mm was adopted.

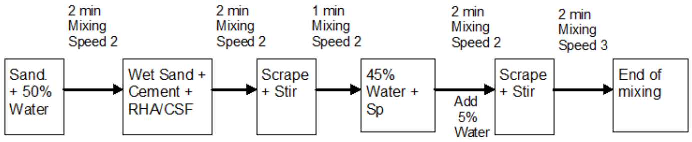


Figure 3: The mixing procedure

3.2 Compressive strength

Mixtures were cast into 50 mm cubic moulds and vibrated for 1 min by using a vibrating table with a frequency of 2500 cycles/min. After casting, samples were covered by polyethylene sheets for one day. After demoulding the samples were stored in water tank until the day of testing. The compressive strength was determined in accordance with BS1881: Part 116: 1983. They were tested at the ages of 1, 3, 7, and 28 days. The compressive strength was average of three samples.

4 RESULTS AND DISCUSSIONS

4.1 Effect of the percentage and fineness and of RHA on workability of fresh concrete

Table 2 shows the amounts of superplasticizer needed in mixtures for achieving a constant flow value from 290 mm to 300 mm. It can be seen mortar containing 20 % RHA need more dosage of superplasticizer compared to that of 10% and 15% RHA. This could be due to the effect of total surface area mortar containing 20% RHA is higher than that of 10% and 15%. Similar results were found by Tuan (2011), who reported that increasing replacement of CSF also increase Sp content (Tuan, 2011).

Figure 4 shows that the amount and the average particle size of RHA influence the workability of RHA mortar. The amount of superplasticizer of mortar increases with an increase of RHA replacement but with the same amount of RHA the dosage of superplasticizer decreases when incorporating less average particle size of RHA.

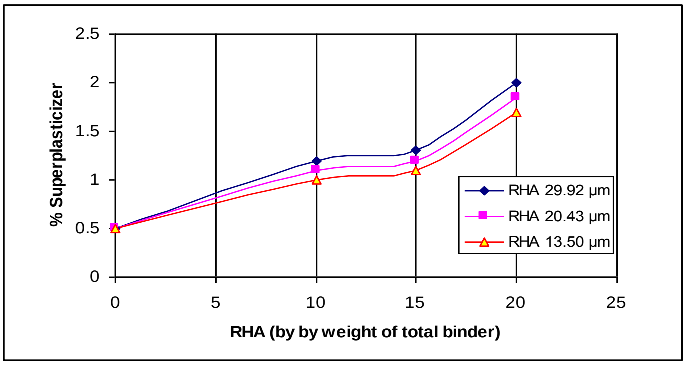


Figure 4: The amount of superplasticizer required for achieving a constant slump flow value of 290 and 300 mm

4.2 Effect of fineness and percentage of RHA on compressive strength of concrete

Figure 5 a, b and c show that OPC and CSF concrete reach compressive strength below 100 MPa and 104 MPa at 28 days respectively. It means that at 28 days, pozzolanic reactions occurred in the CSF concrete. For samples incorporating RHA, with 10% RHA cement replacement the highest compressive strength of HPC was achieved with APS=20.43 µm. At higher replacement level, especially beyond 15%, led to reduction in compressive strength. The use of RHA as a partial replacement of cement exposed the different behavior of compressive strength development. Figure 6 shows that 15% RHA with APS=13.50 µm provided highest compressive strength gain at 28 days. Meanwhile compressive strength of APS = 13.50 µm for 10% and 20% RHA show lower strength than that of 20.43 µm and 22.92 µm. The results are opposite to the finding of Tuan et al. (2011) who reported that higher finess of RHA produced higher strength. It could be the RHA on these mixes were agglomerate and affected the distribution of RHA. Similar situation was reported in SF mixes which show lower strength due to agglomeration (Yajun, 2003). However, Figure 6 a and b show the highest compressive strength of HPC at 3, 7 and 28 days was obtained by using 10% RHA with coarser particle size of RHA, APS=22.92 µm and APS=20.43 µm. Based on this result, it is clear that RHA depending on its average particle size can be used as partial cement replacement at 10% and 15%, to produce HPC 100 MPa. For 20% replacement of cement with RHA, its compressive strength at 28 days is similar to that of OPC concrete but lower than 10% and 15% RHA concrete. The fineness of RHA affects the compressive strength. The finer one has slowly affected the early pozzolanic reaction compared to the coarser one. It could be that the finer material act more as a filler than as pozzolan. Mehta (1979) has mentioned that the grinding of RHA to a high degree of fineness should be avoided due to its pozzolanic activity derives mainly from the internal surface area of the particles (Mehta, 1979).

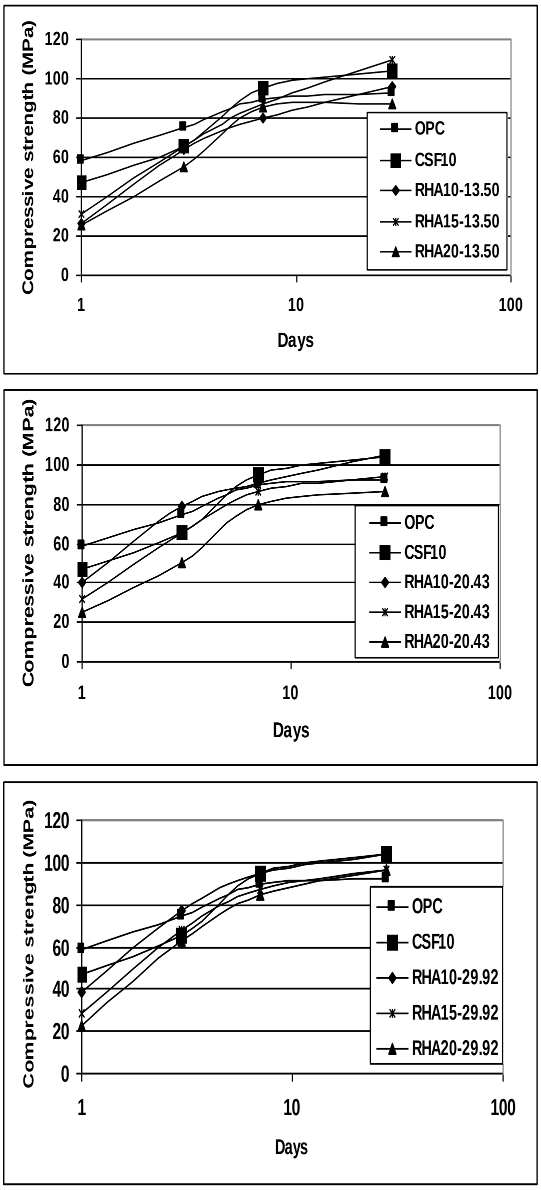
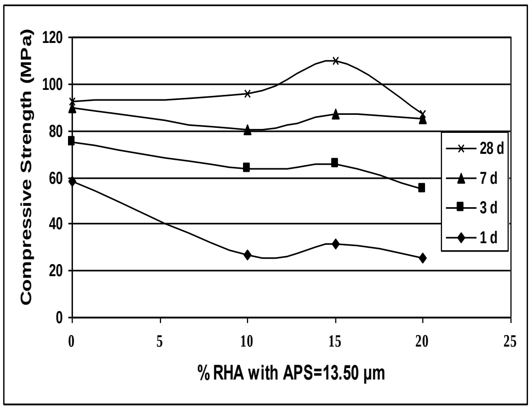


Figure 5: Compressive strength of mortar containing OPC, CSF and several level replacement of RHA



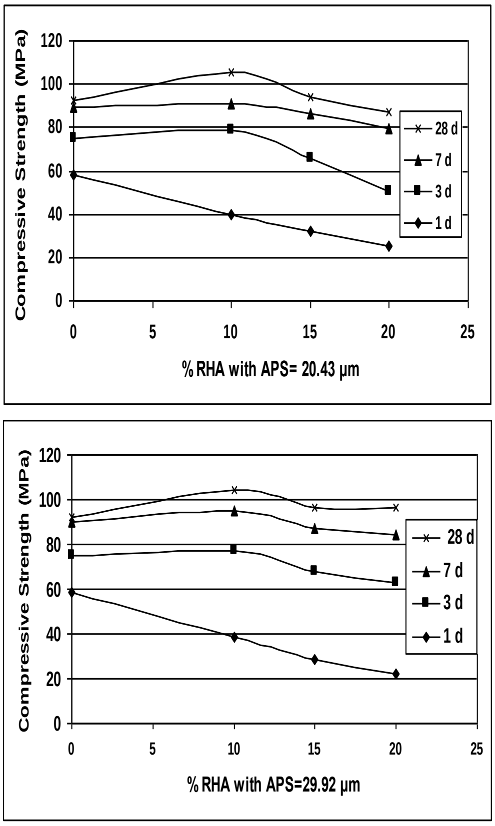


Figure 6: Compressive strength of mortar containing several level replacement of RHA

5 CONCLUSIONS

This paper presents the analytical aspect of compressive strength. It relates to the level of cement replacement and its average particle sizes of RHA in mortar. The main conclusions that can be drawn from the investigation are as follows:

1. Partial replacement of cement by RHA affects the workability of mortar. Increasing the amount of replacement of cement by RHA leads to an increment of total surface area and increased water demand and it can be compensated by increasing dosage of superplasticizer.
2. Incorporating small particle size affects the workability of mortar. At the same level of cement replacement and similar requirement for slump flow, the dosage of superplasticizer decreases.
3. The incorporation of RHA increases the compressive strength of concrete at 7 and 28 days, particularly for 10 % cement replacement. 15 % cement replacement can achieve high compressive strength if smaller particle size RHA, of 13.50 µm is incorporated. For 20% cement replacement, there is not much different between compressive strength of OPC.

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