REPLACEMENT OF CONDENSED SILICA FUME BY RICE HUSK ASH FOR THE PRODUCTION OF HIGH STRENGTH CONCRETE

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Rice husks were incinerated at temperatures below 750^{0}C, yielding an amorphous ash with a significant carbon content that was thereupon grinded for 18 hours in a laboratory ball mill in combination with a naphthalene-based superplasticizer. The grinding resulted in a structural collapse of the porous ash particles, dramatically reducing BET specific surface area. For the concrete specimens with PC contents between 260 and 400 kg/m^3 and significant RHA additions, compressive strength values were obtained exceeding 50 MPa at 7 days, 70 MPa at 28 days and 80 MPa at 180 days. The mortar specimens yielded compressive strength values exceeding at ages of 3, 7, 28 and 182 days respectively 20, 30, 45 and 50 MPa.

INTRODUCTION

Since rice is produced in a significant part of the developing world, rice husk ash (RHA) seems the most appropriate and cheap alternative candidate for condensed slica fume (CSF). RHA is placed by RILEM in the same category of highly pozzolanic materials as CSF.

RHA obtained by controlled combustion of rice husks retains the cellular structure of the husk. It consists essentially of silica in the amorphous form. Due to these features the ash was found to be an excellent component for making either lime-RHA cement, Mehta (2), or portland RHA blended cements.

Because of extremely high porosity the water requirement of the RHA will be higher than CSF with similar specific surface area. This water obviously decreases the mechanical strength of RHA containing composites. The high water demand caused by addition of RHA in concrete mixes can be compensated, as in the case of CSF, by the use of a superplasticizer. Therefore, mixes with low water binder ratios could be employed leading to high strength concrete.

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RHA PREPARATION

For making mortar and concrete specimens rice husks from Tanzania and Vietnam were burnt in larger quantities in an experimental oven specially built in the Stevin Laboratory of Delft University of Technology (see Figure 3). Ashes with various contents of carbon can be obtained by regulating the temperature by means of the rate of air flow and of ash removal. At the end of the ashing process, even under controlled conditions, the ash will generally contain a variable amount of unburnt carbon. This will reduce the silica content accordingly. Nevertheless, in combination with a superplasticizer this component even as high as 23% did not really increase water demand of the cement mortars. Care was taken to ground the ash finely and to properly disperse the binder.

SPECIFIC SURFACE AREA OF RHA

The size of large pores in RHA particles, as seen on electron micrographs, is about 10 microns. According to Hwang and Wu (2) the mean diameter of pores, determined by mercury penetration technique in RHA burnt at temperatures below 700^{0}C, is about 0.5 - 0.6 microns. It can be expected that when particle size of the ash approaches the value of 0.5 - 10 microns, a noticeable drop in specific surface area will occur. Results of the BET specific surface area (TABLE 1) and of particle size distribution analyses show that initially the specific surface area of the RHA after 14 hours of grinding increased from 123 m^2/g (sample D_3) to 151 m^2/g (sample D1). However, after 18 hours of grinding specific surface area was reduced to 137 m^2/g (sample D_2). After 18 hours of grinding with 0.5% superplasticizer a remarkable reduction of BET specific surface area took place (sample D_0). In this sample 75% of the particle size was smaller than 5 microns. Sample D_0 was the finest ash, its BET specific surface area was only 58 m^2/g.

TEST SERIES

Mortar specimens. For the preparation of the mortar specimens two different qualities of RHA were used. The first was produced by grinding the ash for 18 hours in a ceramic laboratory ball mill; this quality is denoted by RHA(18) and is equal to D_2 in TABLE 1. The second quality of RHA was produced similarly, but here the ash was pre-mixed with 0.5% naphthalene-based superplasticizer (VN-BETONMIX 415). This quality is denoted by RHA(18)+ and is represented by D_0 in this table. Two series of mortars were made in which the portland cement was blended with either RHA(18) or with RHA(18)+.

The RHA substitution amounted 10, 15, 20% in the RHA(18) series and 10, 15 and 30% in the RHA(18)+ series (see TABLE 3). A constant amount of superplasticizer of 1.5% by mass of cement was used for both series. All mixtures had a constant consistency of about 110 mm determined on a flow table.

TABLE 1 - BET specific surface area determined by using the Quantachrome Autosorb -6B gas sorption analyser.

sample	grinding	SP	S_{BET}
D_3	0	0	123
D_2	18	0	137
D_1	14	0	151
D_0	18	0.5	58

The (PC+RHA)/sand ratio was 1:2.75. The sand used was a silica sand blended to conform to the graded standard sand of ASTM C109; see TABLE 2. Proportioning and mixing of the mortars were according to ASTM C348. The specimens (40x40x160 mm) were stored under controlled conditions of temperature and humidity (20^{0}C; 95-100% RH) until the day of testing at an age of 3, 7, 28 or 182 days. Specimens were demoulded after one day. Test series encompassed three specimens in flexure, whereupon the six remaining portions were used for compressive strength testing; methods were in accordance with ASTM specifications (ASTM C348 and C349). The compressive strength results are presented in Figures 1 and 2 for respectively the RHA(18) and RHA(18)+ series. At all ages, the compressive strength data of the specimens containing superplasticizer were found about 50% higher as those without superplasticizer. Up till 28 days, the compressive strength of the mortar specimens containing the superplasticizer are quite similar. At an age of 182 days the compressive strength differences are about 30%.

Concrete specimens. From an earlier aggregate grading study of gap-graded mixtures with fine sand, Dong et al (3), three mixtures were selected which yielded for a given water to cement ratio optimum results as to economy and compressive strength. On the basis of these mixtures (C1 to C3) an additional series of 12 mixtures was designed in which sand to gravel ratio and percentage of blending the portland cement with type RHA(18)+ were varied. A series of 100 mm cubes were prepared in two consecutive layers, that were successively compacted for 10 seconds on the vibration table.

For some mixes without superplasticizer, where the workability was low, it was necessary to increase the vibration time. A series of three specimens were tested for compressive strength at an age of 7, 28 or 180 days. Specimens were stored until the day of testing under the same conditions as the mortar specimens. The compressive strength data of the gap-graded concrete mixtures are shown in TABLE 4. As could be expected, introducing super-plasticizer into gap-graded concrete with fine sand improved its workability and strength.

Water to cement ratio and sand to gravel ratio have a marked influence on workability of superplasticized concrete mixes containing RHA. For a given sand

TABLE 2- grading of sand of the mortar specimens

Sieve size mm	% retained
0.149	99.8
0.297	69.8
0.595	4.1
1.19	none

TABLE 3- mix proportions of the mortar specimens

Code	SP %	RHA %	Water/ Binder
PC	0	0	0.470
PC	1.5	0	0.340
RHA	1.5	10	0.365
(18)	1.5	15	0.370
	1.5	20	0.400
RHA	0.5+1.0*	10	0.354
(18)+	0.5+1.0*	15	0.370
	0.5+1.0*	30	0.376

* 0.5% during 18 hours of grinding, plus 1.0% SP extra during preparation.

to gravel ratio workability was directly proportional to the water to cement ratio and water content. On the other hand, workability was inversely proportional to the sand to aggregate ratio provided water to cement ratio was constant. Replacing part of the portland cement by RHA reduced the slump. Mixes with binder (RHA+Cement) content of 500 kg/m^3, water to cement ratio of 0.35, and sand to aggregate ratio of 0.19 to 0.20 have very high workability. In spite of flowable consistency (slump 200 mm) these mixes were very cohesive and without bleeding. TABLE 4 reveals the compressive strength to be significantly improved by combined use of a superplasticizer and the RHA-blended cement even in case of 40% cement replacement. It should be noted, that tests were performed with RHA(18)+. The superplasticizer also increased the compressive strength of concrete, except the mix C1 which shown servere bleeding.

CONCLUSIONS

The present experiments have demonstrated that active rice husk ash obtained under 'realistic' field conditions containing 23% of carbon at temperatures below 750^{0}C can be used to replace a significant portion of the portland cement. The negative effect of unburnt carbon on workability and strength of mortars and concretes can be eliminated by grinding the RHA to particle size smaller than 10 microns, and by using a superplasticizer.

Using the fine ground RHA(18)+ in combination with superplasticizer, the presented experiments demonstrate that for RHA contents up to 30% for the mortar specimens 20 Mpa at 3 days, 30 Mpa at 7 days, 45 Mpa at 28 days and 50 MPa at 182 days can be obtained. Using the fine ash RHA(18)+ in concrete specimens the presented experiments demonstrate that 40% of the cement can be replace by RHA. For cement contents between 260 and 400 kg/m^3, 50 MPa at 7-

days, 70 MPa at 28 days and 80 MPa at 180 days can be obtained, except in the case of a W/C+RHA ratio of 0.55.

TABLE 4- average compressive strength data of gap-graded concretes.

Code	Slump in mm	Duration of vibration in sec	Compressive strength in MPa		
			7 days	28 days	180 days
C1	0	30	25.9	23.6	-
C2	0	30	40.3	50.4	-
C3	0	30	48.3	55.4	-
C1*)	10	20	22.2	30.8	38.5
C2	30	20	43.9	56.1	70.7
C3	20	20	47.9	61.2	66.3
C1	10	20	29.8	47.1	54.6
C2	25	20	44.7	64.3	72.3
C3	15	20	50.4	69.9	76.2
	6	20	47.3	70.2	81.3
	15	20	53.8	69.1	81.6
	200	20	50.3	68.9	80.4
	8	20	56.9	73.7	90.1
	200	20	51.6	70.1	83.6
	200	20	52.5	70.5	86.4

*) severe bleeding

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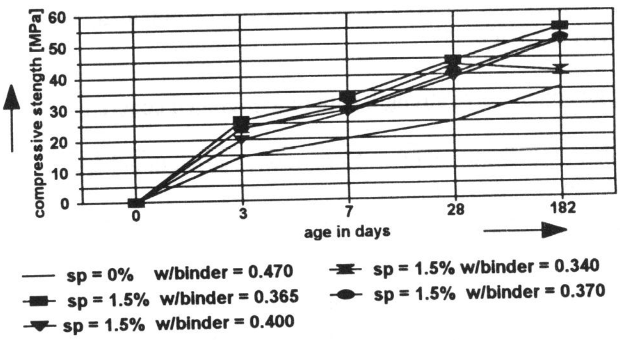

Figure 1 Compressive strength data of the RHA(18) mortar series

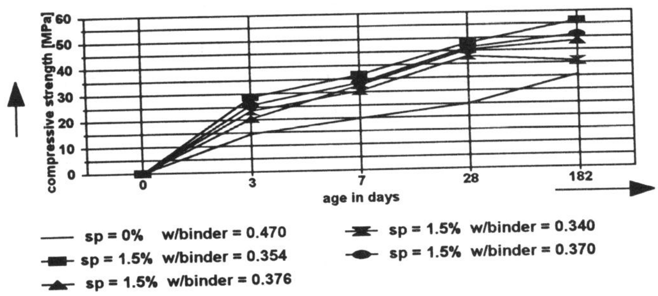

Figure 2 Compressive strength data of the RHA(18)+ mortar series

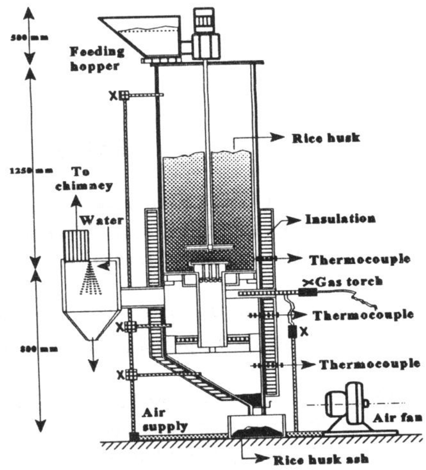

Figure 3 Experimental oven