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SELF-COMPACTING CONCRETE CONTAINING UNTREATED-MIXED FLY ASH AND RICE HUSK ASH, PART II: HARDENED CONCRETE CHARACTERISTICS

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ABSTRACT

We evaluated the hardened characteristics of self-compacting concrete (SCC) mixtures containing rice husk ash (RHA) and fly ash (FA). The rice husk ash was used as a fine aggregate replacement at levels of 0% and 25% and the fly ash was used as a cement replacement at levels of 0, 20, 40 or 60% by volume. Trials were conducted to determine the water content required to produce SCC mixtures with a slump flow of 70 ± 2.5 cm. The hardened properties tests including compressive strength and ultrasonic pulse velocity were measured at 3, 7, 28, 91 and 180 days. The results demonstrate that the optimum ash content was 20-40% and the optimum rice husk ash content was 25%, resulting in an optimum SCC mixture with the compressive strength of 30-40 MPa.

KEYWORDS : Self-compacting concrete, Fly ash, Rice husk ash, Hardened characteristics

1. Introduction

One of the most significant recent developments in the construction industry has been the formulation of concrete mixtures capable of being compacted solely by gravity, avoiding the need for vibratory compaction. Self-compacting concrete (SCC) can be placed and compacted under its own weight with little or no vibration. It has three essential fresh state properties; filling ability, passing ability and segregation resistance [1]. To meet these requirements, SCC mixtures contain limited amounts of aggregate, low water-binder ratios, and superplasticizer admixtures [2]. The high homogeneity of SCC enables it to bond well with reinforcing steel to provide adequate structural performance and durability [3]. Powder materials include cementitious and filling materials could increase the workability of the concrete without increasing its cost [4].

Fly ash (FA) is a by-product of thermal power plants and has been reported to improve the workability and mechanical properties of concrete when used as a cement replacement material [1,5-6] and also affected by the replacements and the fineness of fly ash [7]. Khatib [8] have reported that high volumes FA may be used in SCC mixtures to produce high strength and low shrinkage. High absorption values were obtained with increasing amounts of FA. Replacing 40% or 60% of the cement with fly ash resulted in strengths of 65 or 40 MPa at 56 days. The compressive strength increased with decreasing fly ash content and water-to-cement ratio [4,9]. Rice husk ash (RHA) containing silica-rich content, can be used in concrete as a supplementary cementitious material. The pozzolanic activity of RHA depends on its physical characteristics and chemical composition, The higher compressive strength of the RHA concrete is due probably to densify concrete and to reduce $Ca(OH)_2$ content and the width of interfacial zone between the paste and the aggregate [10-12]. In addition, unground RHA may also be used as a fine-aggregate replacement [13] and the use as a pozzolan-blend material more advantageous to concrete due to the synergic chemico-particle filling effects [14].

The objective of this study was to evaluate the hardened characteristics of SCC mixtures incorporating fly ash as a partial cement replacement and as-received residual rice husk ash as a partial fine aggregate replacement.

2. Materials used

2.1 Cement and mineral admixtures

An ordinary Type 1 Portland cement (OPC) conforming to ASTM C150 [15] was used in all of the mixtures. Fly ash (FA) was obtained from Mae Moh power plant in Lampang province in the northern part of Thailand. Rice husk ash (RHA) was obtained from a power plant located in Chainat province in the central part of Thailand. The ash was retrieved from a large open dump pile and was dried and homogenized before use. The chemical compositions and physical properties of the ash materials are listed in Table 1. The particle size distributions of the OPC, FA and RHA were determined using a laser granulometer and are depicted in Figure 1.

2.2 High range water reducing admixture (HRWRA)

A polycarboxylic ether-based superplasticizer conforming to ASTM C494 [16] standard type F with a specific gravity of 1.05 and a solid content of 42% was added to all of the mixtures.

Table 1 Chemical composition and physical properties of SCC components.

Oxide	OPC	FA	RHA
Chemical composition (% by mass)			
Silicon dioxide (SiO_2)	16.39	40.51	93.44
Alumina oxide (Al_2O_3)	3.85	21.52	0.21
Ferric oxide (Fe_2O_3)	3.48	13.41	0.18
Magnesium oxide (MgO)	0.64	2.10	0.43
Calcium oxide (CaO)	68.48	13.99	0.76
Sodium oxide (Na_2O)	0.06	1.44	0.05
Potassium oxide (K_2O)	0.52	2.20	1.98
Sulfur trioxide (SO_3)	4.00	4.00	0.16
SiO_2+Al_2O_3+Fe_2O_3	23.72	75.44	93.83
Physical properties			
Loss on Ignition (% by mass)	1.70	0.49	1.27
Mean Particle size (μm)	23.32	43.86	39.34
Specific gravity	3.15	2.26	2.20
Specific surface area-BET method (cm^2/g)	6100	14870	3700

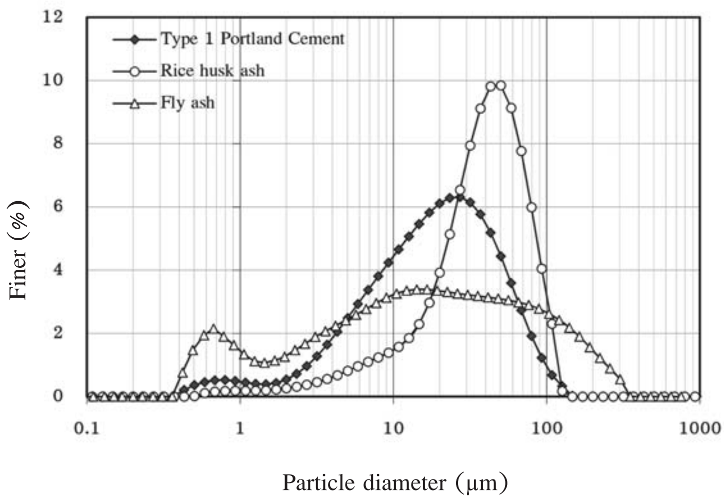

Figure 1 Particle size distributions of cement, fly ash and rice husk ash

2.3 Aggregates

The fine aggregate consisted of locally available natural sand with a maximum particle size of 4.75 mm. The coarse aggregate was crushed stone with a maximum size of 16 mm. Gradation of the aggregate materials conformed to the requirements of ASTM C33 [17]. The physical properties of the fine and coarse aggregates are provided in Table 2.

Table 2 Properties of fine and coarse aggregates.

Properties	Fine aggregate	Coarse aggregate
Fineness modulus	2.59	7.84
Absorption (%)	0.71	1.52
Maximum size (mm)	4.75	15
Bulk density (kg/m^3)	1645	1528
Specific gravity	2.65	2.71

3. Mix proportions

A total of 8 SCC mixes were prepared with binder contents ranging from 457-550 kg/m^3 and fly ash contents of 0, 20, 40, or 60% by volume (Table 3). The coarse aggregate content was kept constant at 708 kg/m^3. RHA was used to replace 0 or 25% of the fine aggregate by volume. The mixtures were prepared to yield a slump flow diameter of 70 ± 2.5 cm. Each mixture was identified using the form FAxRy in which x and y are the volume percentages of cement replaced by y ash and natural sand replaced by rice husk ash.

Table 3 Mixture proportions of SCC

Materials	0% Fly ash		20% Fly ash		40% Fly ash		60% Fly ash	
	FA0R0	FA0R25	FA20R0	FA20R25	FA40R0	FA40R25	FA60R0	FA60R25
Cement (kg/m^3)	550	550	440	440	330	330	220	220
Fly ash (kg/m^3)	0	0	79	79	158	158	237	237
Coarse ggregate(kg/m^3)	708	708	708	708	708	708	708	708
Fine aggregate(kg/m^3)	813	609	813	609	813	609	813	609
Rice husk ash(kg/m^3)	0	169	0	169	0	169	0	169
Water (kg/m^3)	110	270	114	273	106	274	88	229
HRWR (%)	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2

4. Testing procedures

The hardened properties were determined using compressive strength and ultrasonic pulse velocity (UPV) tests conducted according to the procedures in ASTM C39 [18] and ASTM C597 [19]. The test specimens were prepared in triplicate as 150 mm diameter and 300 mm long cylinders without compaction. The specimens were covered with a plastic sheet while curing. After removal from the moulds at 24 h, the specimens were immersed in lime-saturated water until testing at 3, 7, 28, 91, and 180 days.

5. Results and discussion

The compressive strength and ultrasonic velocity of hardened concrete samples were measured at 3, 7, 28, 91, and 180 days following casting. The reported values are the mean values of measurements performed on three specimens as shown in Table 4.

Table 4 Properties of hardened SCC mixtures.

Mix	Compressive strength (MPa)					Ultrasonic pulse velocity (m/s)				
	3-days	7-days	28-days	91-days	180-days	3-days	7-days	28-days	91-days	180-days
FA0R0	21.6	42.0	52.5	61.1	71.8	3030	3360	4000	4650	5270
FA0R25	16.6	29.0	35.8	42.5	53.2	2550	3030	3690	4320	5000
FA20R0	19.1	36.9	49.7	59.3	69.3	2910	3210	3880	4550	5180
FA20R25	11.5	19.9	25.7	31.6	40.1	2440	2730	3290	3910	4590
FA40R0	17.8	33.1	41.8	51.8	62.4	2710	3120	3680	4290	5050
FA40R25	7.6	15.8	21.1	26.5	32.5	2300	2680	3000	3560	4180
FA60R0	14.0	22.9	31.6	38.5	47.4	2570	2910	3440	4070	4780
FA60R25	6.4	11.5	15.3	20.1	25.7	2230	2600	2880	3380	3830

5.1 Compressive strength

The compressive strength continued to increase over the 180-day curing period. Mixtures containing no RHA had compressive strengths ranging from 14 to 21.6 MPa at 3 days, 22.9 to 42.0 MPa at 7 days, 31.6 to 52.5 MPa at 28 days, 38.5 to 61.1 MPa at 91 days, and 47.4 to 71.8 MPa at 180 days. Increasing addition of FA generally decreased the strength, confirming the results of previous investigations [1,4-6,8-9]. Incorporation of fly ash resulted in lower pore sizes due to the gradual filling of large pores from factors such as hydration reactions, nucleation effects, packing effects, and pozzolanic reactions of fly ash particles [7]. The reduced compressive strength is possibly due to the reduced cement content [14], and slower pozzolanic reactions of fly ash with $Ca(OH)_2$ in the hydrated cement [1].

At 25% replacement of fine aggregate with RHA, the compressive strengths ranged from 6.4 to 16.6 MPa at 3 days, 11.5 to 29.0 MPa at 7 days, 15.3 to 35.8 MPa at 28 days, 20.1 to 42.5 MPa at 91 days, and 25.7 to 53.2 MPa at 180 days. The compressive strength of SCC containing RHA was lower, in agreement with previous reports [13-14]. The cellular shape of RHA creates water absorption problems in damp surroundings [10], and the increased porosity with the incorporation of RHA also increases the water-binder ratio [11,13].

5.2 Ultrasonic pulse velocity

Ultrasonic pulse velocity (UPV) testing is a non-destructive technique for evaluating the homogeneity of concrete. The ultrasonic pulse velocity is related to the density and elastic properties of the constituent materials and may be used to assess the strength of concrete for a given aggregate content and moisture condition [1,13]. UPV increased with increasing compressive strength in all of the mixtures. The ultrasonic pulse velocities continued to increase over the 180-day curing period. SCC mixtures that did not contain RHA had ultrasonic pulse velocities ranging from 2570 to 3030 m/s at 3 days, 2910 to 3360 m/s at 7 days, 3440 to 4000 m/s at 28 days, 4070 to 4650 m/s at 91 days, and 4780 to 5270 m/s at 180 days.

Increased FA content generally resulted in a decrease in ultrasonic pulse velocity, in agreement with previous investigations [8]. The addition of fine FA particles results in pore refinement and a reduction of free calcium hydroxide in the cement paste. SCC mixtures containing FA were slightly less porous than those containing only RHA, suggesting that FA is slightly more effective in modifying pore size and reducing the porosity of concrete. However, greater amounts of fly ash increased the porosity due to the reduced amount of cement. The reduced cement content resulted in the presence of fewer hydration products, particularly at early stages when pozzolanic reactions had not yet achieved their full rate [11]. In addition, the fly ash increased the void space between cement particles [1].

In mixtures containing 25% RHA the ultrasonic pulse velocities were 2230 to 2550 m/s at 3 days, 2600 to 3030 m/s at 7 days, 2880 to 3690 m/s at 28 days, 3380 to 4320 m/s at 91 days, and 3830 to 5000 m/s at 180 days, lower than in non-RHA mixtures due to the increased porosity and cellular structure of the hardened concrete [10]. The addition of coarse particles of RHA may produce large pores and decrease the number of nucleation sites available for precipitation of hydration products in the concrete [14]. The porosity was reduced during extended curing due to the increase in hydration of cementitious materials and pozzolanic activity of RHA [12] and the reduction in fine aggregate content [1, 13].

5.3 Correlation of mechanical properties of SCC

The relationship between the compressive strength, ultrasonic pulse velocity, and fly ash content is depicted in Figure 2. The addition of large amounts of FA caused a reduction in compressive strength. The compressive strength was directly correlated with ultrasonic pulse velocity in all of the mixtures, and the correlations were independent of the amount of fine aggregate replaced. The correlation coefficients (R^2) were 0.8614, 0.8306, 0.8714, and 0.9052 for FA contents of 0, 20, 40, and 60%. Similar results were obtained in previous studies in which these properties were measured in SCC mixtures. The correlations in these studies also appeared to be independent of FA content [1,8]

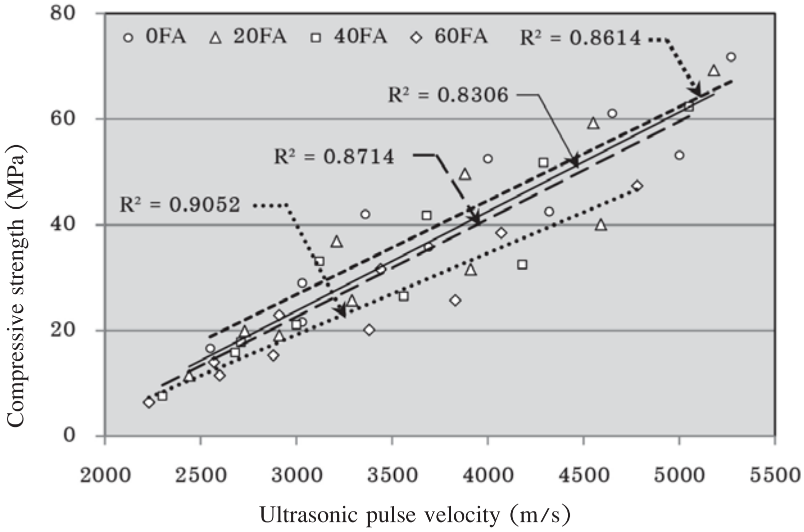

Figure 2 Relationship between compressive strength and ultrasonic pulse velocity for mixtures containing various amounts of fly ash.

The relationship between compressive strength and ultrasonic pulse velocity as a function of rice husk ash content is illustrated in Figure 3. The incorporation of RHA caused a reduction in compressive strength. The compressive strength increased with increasing ultrasonic pulse velocity in all of the mixtures. Good correlations were obtained between compressive strength and ultrasonic pulse velocity independent of FA content. The correlation coefficients (R^2) were 0.8967 and 0.8976 for mixtures containing 0 and 25% RHA. The correlations were similar to those obtained in previous studies, which also reported correlations independent of RHA. content [13].

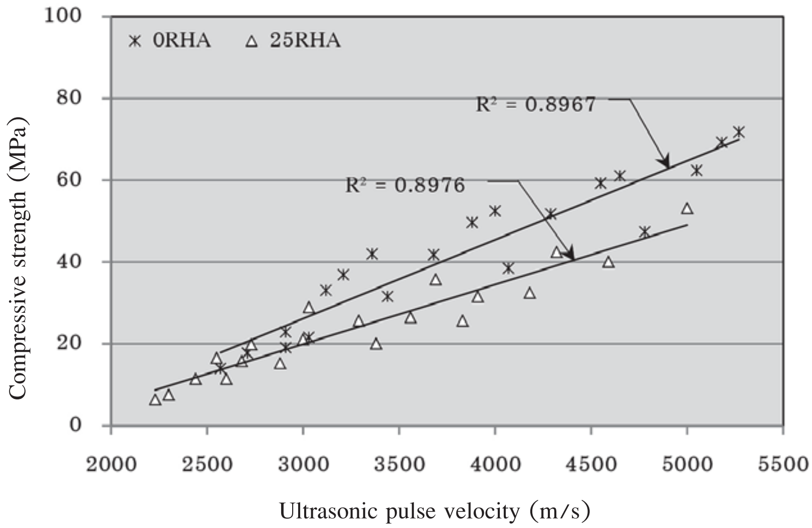

Figure 3 Relationship between compressive strength and ultrasonic pulse velocity for mixtures containing various amounts of rice husk ash

The compressive strength of each mixture is plotted as a function of water-binder-ratio (w/b) in Figure 4. The correlation coefcients (R2) were 0.5939, 0.5672, 0.6273, 0.6459, and 0.6303. The compressive strength decreased with increasing water-binder ratio at all ages, and incorporation of RHA increased the required water-binder ratio and decreased the compressive strength in a manner similar to previous studies investigating these properties in SCC mixtures containing bottom ash [9]. A comparison between SCC with various FA and RHA contents indicated that the SCC mixtures increased in strength when the water-binder ratio was increased from 0.19 to 0.24 for 0% RHA and 0.49-0.55 for 25% RHA. A common method of achieving self-compactability is to use a low water-binder ratio [3], hence the water-binder ratio has signicant effects on both the fresh and hardened properties, and often its effect on the fresh properties limits the range of acceptable values and is frequently the most signicant determinant of compressive strength [2,9].

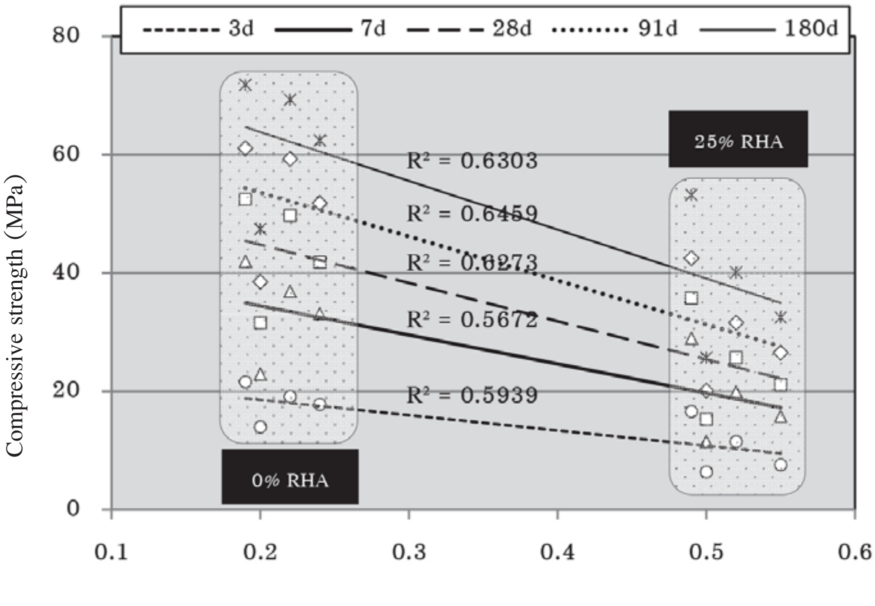

Figure 4 Relationship between compressive strength and water-to-binder ratio at 3, 7, 28, 91 and 180 days

6. Conclusions

The present investigation has demonstrated that the compressive strength and ultrasonic pulse velocity decreased with increases in y ash content and water-cement ratio. Incorporating as-received rice husk ash as a ne aggregate replacement resulted in a decrease in compressive strength and ultrasonic pulse velocity. Both compressive strength and ultrasonic pulse velocity increased with age in all of the mixtures.

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