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

Natt Makul[1] and Gritsada Sua-iam[1,2]
[1]Department of Building Technology, Faculty of Industrial Technology,
Phranakhon Rajabhat University, 9 Changwattana Road, Bangkhen Bangkok, 10220, Thailand (+662) 544-8275
E-mail: shinomomo7@gmail.com[1], cm_gritsada@hotmail.com[2]

Abstract

We evaluated the fresh 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. Fresh ability tests including water requirement, T_{50cm} *slump flow, J-ring flow and V-funnel flow were performed on each mixture. The results demonstrate that the addition of fly ash improved the workability of the SCC mixtures, but addition of fly ash and rice husk ash increased the required water-binder ratio.*

1. Introduction

Self-compacting concrete (SCC) was developed in Japan in 1988 to produce durable concrete structures during a period in which few skilled construction workers were available. SCC technology has rapidly evolved from an exploratory stage to routine use in many parts of the world [1]. The mixtures exhibit a low resistance to flow, moderate viscosity, high deformability, and high homogeneity, enabling them to deform and flow through restricted sections of formwork. In order to prevent blockage of concrete flow among closely spaced obstacles, concrete should have adequate cohesiveness [2]. To produce a homogeneous and cohesive mix, SCC demands a larger binder content than conventional vibrated concrete [3]. Domone [4] studied 68 SCC applications, 80% of which contained 445–605 kg/m^3 of binder. SCC mixtures containing only cement are costly and susceptible to thermal cracking, and autogenous shrinkage. It is therefore necessary to replace cement with additional materials [5].

Previous studies have estimated that approximately 3.5 million tons of fly ash are produced annually in Thailand, and only half of this material is utilized [6]. It is well established that the use of FA in concrete can reduce water requirement for a given workability. Therefore, concrete containing FA improves viscosity while not to decrease the flowing ability based on the particle characteristics [7-10]. Studies shown that it is possible to design an SCC mix incorporating fly ash content up to 35% [11]. Rice production is a major agricultural sector in Thailand, where nearly 32 million tons of rice was produced in 2011 [12]. Rice husks are often used for energy generation in biomass-fueled electric power plants, forming rice husk ash (RHA) whose physical characteristics and chemical composition with imparts the pozzolanic properties [13]. Unground RHA may also be used as a fine-aggregate replacement. The amount of fine aggregate replaced with unground RHA could be substantially increased when combined with other filler materials [14]. The use of RHA/FA blends at low replacement levels improved the late-stage strength of concrete mixtures [15]. The objective of this study was to evaluate the fresh characteristics of SCC mixtures incorporating fly ash as a partial cement replacement and as-received (untreated) residual rice husk ash as a partial fine aggregate replacement.

2. Materials used

2.1 Cementitious materials

A Type 1 Portland cement (OPC) conforming to ASTM C150 [16] 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 using a laser granulometer (Malvern Mastersizer) were displayed in Figure 1.

2.2 High range water reducing admixture (HRWRA)

A polycarboxylic ether-based superplasticizer conforming to ASTM C494 [17] 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)			
SiO_2	16.39	40.51	93.44
Al_2O_3	3.85	21.52	0.21
Fe_2O_3	3.48	13.41	0.18
MgO	0.64	2.10	0.43
CaO	68.48	13.99	0.76
Na_2O	0.06	1.44	0.05
K_2O	0.52	2.20	1.98
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 (cm^2/g)	6100	14870	3700

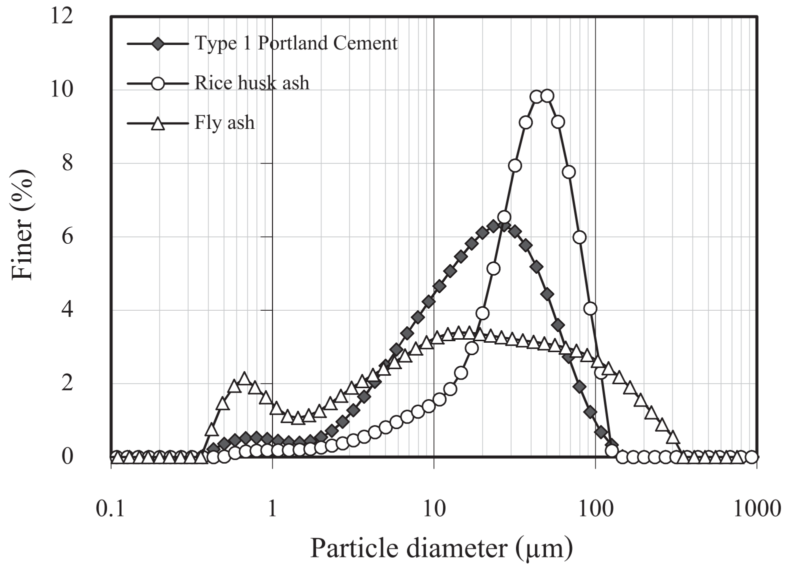


Figure 1 Particle size distributions of cement, fly ash and rice husk ash plotted using semi-logarithmic scale

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 [18]. 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	15.0
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 fly ash and natural sand replaced by rice husk ash.

4. Testing procedures

The workability of the SCC mixtures was evaluated based on slump flow, T_{50cm} flow time, J-ring flow, and V-funnel flow as presented in Figure 2.

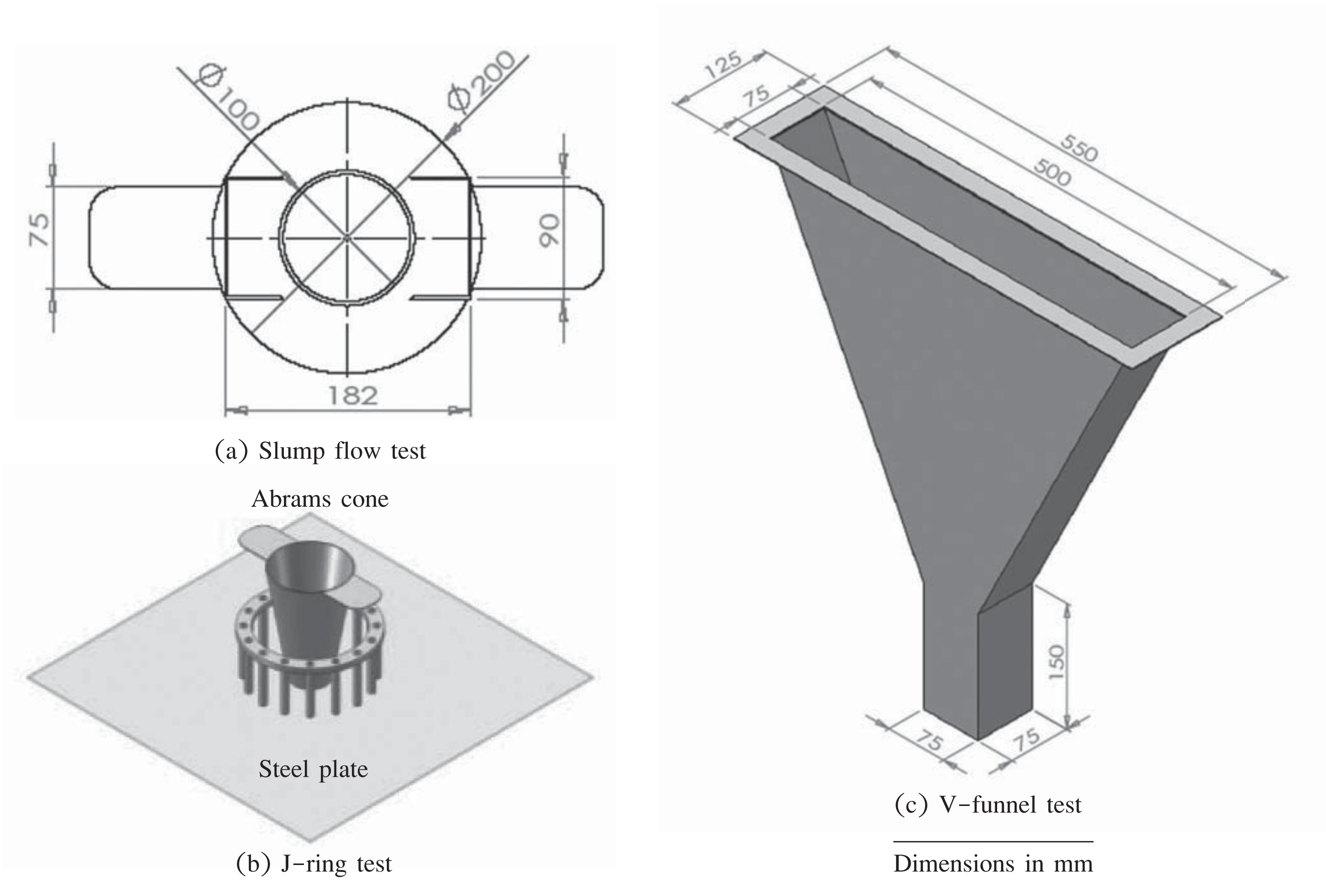
The densities of the freshly-prepared SCC mixtures were measured as specified in ASTM C138 [19]. The controlled slump flow diameter of 70 ± 2.5 cm was selected as being within the acceptable range published in the EFNARC guidelines [20], as flows of greater than 70 cm may cause segregation [8]. The slump flow test was performed using an inverted mould without compaction and the reported spread diameters are the averages of four measurements. The time required to reach 50 cm from the time the mould was first raised was used to provide a relative measure of the confined flow rate of the concrete mixture in accordance with ASTM C1611 [21].

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 aggregate (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
HRWR (%)	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2

The V-funnel test was used to evaluate the viscosity of the mixtures. A V-shaped funnel was filled with fresh concrete and the time required for the concrete to flow out of the funnel was measured and recorded according to the procedure outlined in the EFNARC guidelines [20].

The blocking behaviour of the mixtures was investigated using the J-ring test. The difference between the slump flow and J-ring flow is an indicator of the passing ability of the concrete based on ASTM C1621 [22].



(a) Slump flow test

(b) J-ring test

(c) V-funnel test

Figure 2 Workability test apparatus

5. Results and discussion

5.1 Water requirement

The water-binder ratios that resulted in slumps of 70 ± 2.5 cm diameter in each mixture as shown in Table 4. With a fixed amount of superplasticizer, the workability of fresh concrete depends on the binder and water content [8]. To maintain the desired slump flow, SCC mixtures containing 25% RHA required water-binder ratios between 0.49 and 0.55, substantially higher than the water-binder ratios between 0.19 and 0.24 used in mixtures containing no RHA. The increase is due to the porous structure, residual carbon, and small particle size of rice husk ash as well as the substantial RHA-induced increase in binder surface area. The increased surface area adsorbs a greater amount of water, decreasing the quantity of free water available in the mixture [14].

Table 4 Properties of fresh SCC mixtures.

Mix	Slump flow		J-ring test		V-funnel time (s)	Water requirement		Density (kg/m^3)
	Diameter (cm)	T_{50cm} (s)	Diameter (cm)	Blocking		w/c	w/b	
FA0R0	72	3	70	No	10	0.20	0.20	2611
FA0R25	70	4	68	No	12	0.49	0.49	2506
FA20R0	70	4	70	No	8	0.26	0.24	2549
FA20R25	70	4	70	No	10	0.62	0.52	2420
FA40R0	72	4	70	No	9	0.32	0.22	2521
FA40R25	70	5	70	No	11	0.83	0.55	2337
FA60R0	70	4	70	No	9	0.40	0.19	2393
FA60R25	70	5	70	No	12	1.04	0.50	2294

The water to binder ratio in the mixtures containing fly ash was 0.06 in mixtures containing 25% RHA and 0.05 in mixtures containing 0% RHA. In general, the use of FA in concrete reduces the water demand [7] due to filling and lubricating effects. However, these effects are not strong enough to offset the increased water requirement resulting from the increase in surface area. Because the specific surface area of fly ash is greater than the specific area of cement, the total surface area and water demand of the system will increase when cement is replaced by fly ash [10]. In this studied, the ACI 211.1-91 standard practice describes methods for selecting proportions for concrete. The total binder content decreased from 550 to 457 kg/m^3 as the FA fraction was increased to 60%, and therefore the reduced water demand did not affect the water-binder ratio. This relationship suggests that SCC should be formulated based on binder composition and not water-binder ratio as in conventional concrete [4].

5.2 Workability

The workability requirements for SCC include excellent deformability, good stability, and resistance to segregation between the coarse aggregate and mortar as the concrete flows through confined regions between reinforcements [2]. These properties were evaluated based on slump flow, V-funnel, and J-ring tests. Table 4 lists the results of tests performed on the fresh concrete mixtures, as well as the water-binder and water-cement ratios (w/b and w/c), blocking assessment, and density of each mixture. The workability test results were within the limits described in the relevant specifications and guidelines [20, 22] for rheological characteristics and self-compactability.

All of the SCC mixtures exhibited a satisfactory average slump flow of 70 ± 2.5 cm diameter, indicating good deformability. Slump flow time testing is used to evaluate the flowability of self-compacting concrete and is determined according to ASTM C1611 [21]. The time required to reach a diameter of 50 cm was within the acceptable range of 3-5 seconds for all mixtures. The slump flow time increased with increasing FA content and in mixtures containing RHA. The flow time increased with increasing FA content and decreasing water content [5]. The greater slump flow time may have been due to the increased surface area of FA, the affinity of RHA for water (which increases the viscosity of the paste), and improved packing resulting from the fineness of the FA particles [9, 14].

The gradually reducing cross section present in the V-funnel flow test provides an indication of both internal and external friction. The V-funnel flow time is defined as the time in seconds between the opening of the bottom outlet and the time at which light becomes visible from the bottom [11]. The flow time specified in the EFNARC acceptance criteria is 8-12 s [20]. All of the SCC mixes met the flow time requirements. The flow time increased with the addition of RHA due to water absorption by this material, which resulted in a highly viscous mixture and segregation of fine aggregate particles [14]. On the other hand, the V-funnel flow time decreased with increasing FA content due to differences in particle size, shape, and specific surface area between fly ash and cement [9].

The J-ring test is used to evaluate important characteristics such as passing ability and segregation resistance. When the filling cone is lifted, the concrete flows through an array of reinforcing bars. The differences in the slump flow and J-ring flow diameters were used to obtain the blocking assessments in Table 3. The blocking assessments were assigned based on ASTM C1621 [22], in which a difference of 0 - 2.5 cm (0 - 1 in) is defined as no visible blocking, 2.5 - 5 cm (1 - 2 in) is defined as minimal to noticeable blocking, and greater than 5 cm (2 in) is defined as noticeable to extreme blocking. The J-ring diameters ranged from 68 - 70 cm, making the differences in slump flow and J-ring flow diameters between 0 and 2 cm. Performance standards generally require a blocking ratio of not more than 5 cm. All of the mixtures achieved adequate passing ability and maintained sufficient resistance to segregation around congested reinforcement areas, indicating that when the mixture has no obvious segregation, the slump remains quite constant with increased water content [8]. Incorporation of fly ash improved the segregation resistance and the viscosity of fresh concrete in a manner similar to a viscosity agent, without a decrease in flowability [5]. The segregation index was lower in SCC mixtures containing FA [9]. Replacement of river sand with RHA provided increased surface area and a greater amount of water absorption, also increasing the viscosity and reducing segregation [2, 14].

5.3 Density

The density of each mixture is provided in Table 4. The density decreased with increasing RHA content and increased with increasing FA content. The variations in concrete density corresponded to variations in the proportions of cement (specific gravity 3.15), FA (specific gravity 2.26), natural river sand (specific gravity 2.67), and RHA (specific gravity 2.20).

6. Conclusions

The present investigation has demonstrated that at constant slump flow diameter, inclusion of RHA required an increase in water-binder ratio. In addition, replacement of cement with fly ash required slightly different water-binder ratios at constant superplasticizer dosage. It is possible to design SCC mixes incorporating fly ash and as-received rice husk ash. Mixtures incorporating fly ash up to 60% had slump flow, flow time, and blocking assessments within published specifications.

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