Effect of limestone powder on the properties of self-consolidating concrete mixed with rice husk ash

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Abstract

We evaluated the feasibility of using limestone powder (LS) as a modifying agent in self-consolidating concrete containing untreated rice husk ash (RHA) as a partial replacement for the fine aggregate. Mixtures were designed to produce a controlled slump flow diameter. A constant Portland cement content was maintained for all concrete mixtures. The fine aggregate was replaced with levels at 20% RHA and LS by volume. The T_{50} slump flow, J-ring flow, V-funnel flow, ultrasonic pulse velocity and compressive strength of the SCC mixtures were tested, and a blocking assessment was performed. The properties of hardened SCCs containing LS were superior, and the properties of fresh and hardened SCCs containing RHA were substantially improved when RHA was combined with LS. The results demonstrate that LS has the potential to improve the properties of SCC when untreated RHA is used as a partial replacement of fine sand.

1. Introduction

Since its introduction in 1988 in Japan to address a lack of skilled workers Self-consolidating concrete (SCC) has gained wide acceptance in the construction industry [1]. SCC flows under its own weight while maintaining resistance to segregation. Fresh SCC must be stable to ensure homogeneity and mechanical strength in the finished structure. However, several problems may occur in some formulations, including bleeding, settlement, and segregation [2].

Superplasticizers are used to improve the flowability of SCCs without causing deformation or segregation problems. Mixtures containing moderate amounts of cementitious materials and fine fillers decrease the coarse aggregate volume and reduce the risk of blockage while simultaneously increasing the segregation resistance and reducing the costs associated with high volumes of Portland cement and superplasticizer [3]. Mineral admixtures such as fly ash, limestone (LS) powder, and rice husk ash (RHA) have been used as alternative approaches to improved SCC properties [4-6].

According to previous studies, residual RHA may be used without grinding, by adapting the mixing process to optimize the ash particle size [7]. The incorporation of RHA in SCC decreases the unit weight, flowability, water absorption, total porosity, compressive strength, ultrasonic pulse velocity (UPV), and cost, but increases the electrical resistivity [6,8]. As a potentially valuable resource produced during stone-crushing operations, LS is the most common additive to improve the flowability of SCC [13]. When LS is used, the initial and final concrete setting times are shorter and the total shrinkage is only slightly greater than those values in conventional concrete [14]. The LS filler also acts as a viscosity enhancer, increasing the workability [15].

The objective of this study was to investigate the use of as-received (untreated) residual RHA as a partial fine aggregate

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replacement. Satisfactory RHA particle size may be obtained by mixing RHA with the remaining fine and coarse aggregates. The elimination of grinding costs increases the feasibility of using RHA in concrete production.

2. Experimental

2.1 Material

The Type 1 Portland cement (OPC) used in this study complied with ASTM C150 [12], RHA was obtained from the Electrical Power Plant in Chainat Province of Thailand, the ash was only dried and homogenized. The LS powder was obtained from an industrial rock crushing plant located at Saraburi Province of Thailand.

The particle size distributions of the Portland cement (OPC) and Limestone powder (LS) were determined using a laser granulometer (Malvern Mastersizer) and are depicted in Figure 1. The particle morphology was examined using a scanning electron microscope (SEM). Figures 2a-c are SEM image obtained at approximately 1000x magnification.

The chemical compositions and physical properties of the cement, untreated RHA, and LS powder are listed in Table 1.

Table 1 Chemical composition and physical properties of SCC components.

Oxide	OPC	RHA	LS
Chemical composition (% by mass)			
SiO_2	16.39	93.00	8.97
Al_2O_3	3.85	0.35	1.02
Fe_2O_3	3.48	0.23	0.37
MgO	0.64	0.41	2.38
CaO	68.48	1.31	46.77
Na_2O	0.06	0.15	0.02
K_2O	0.52	1.61	0.13
SO_3	4.00	0.09	0.33
Physical properties			
Loss on Ignition (% by mass)			
	1.70	1.90	39.54
Particle size distribution (μm)			
	23.32	84.32	15.63
Specific gravity			
	3.2	2.2	2.76
Specific surface area(m^2/kg)			
	610	240	1300

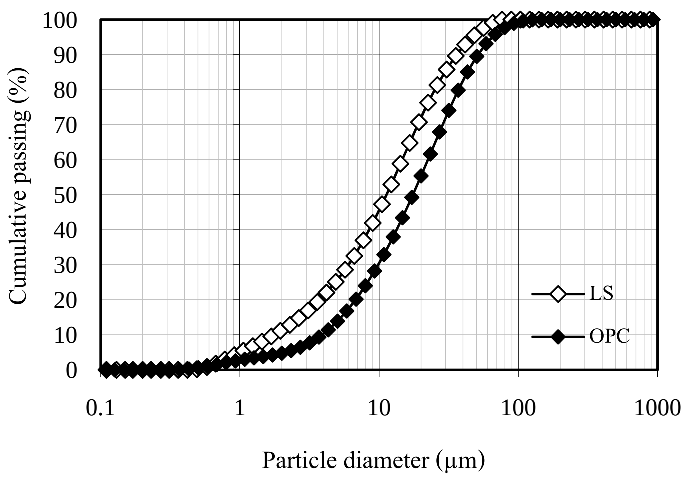
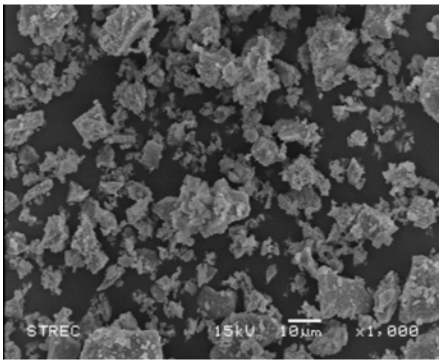
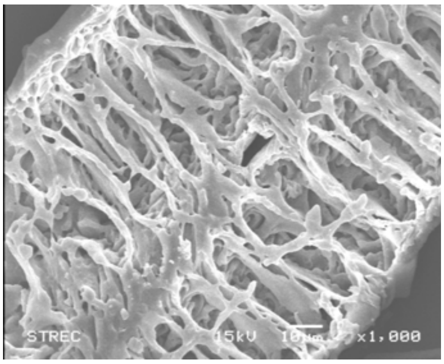


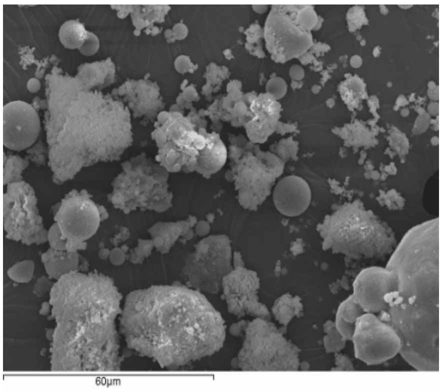
Figure 1 Particle size distribution of cement and limestone powder plotted using semi-logarithmic scale



(a) Type 1 Portland cement (OPC)



(b) Rice husk ash



(c) Limestone powder

Figure 2 Scanning electron micrographs (1000x) of (a) Type 1 Portland cement (OPC), (b) rice husk ash, and (c) limestone powder.

To obtain the desired fluidity of the SCC, a polycarboxylate-based high range water- reducing admixture [HRWR] conforming to ASTM C494 [12] standard type F was used in the mixtures at a concentration of 2.0 wt% of the binder materials. The solid content and specific gravity of the HRWR were 42% and 1.05, respectively.

2.2 Mix proportions

The compositions of the SCC mixtures are presented in Table 2. The compositions of the cement and coarse aggregate were kept constant at 550 kg/m^3 and 708 kg/m^3, respectively, in all mixtures. Combinations of RHA and/or LS were used to replace the river sand in amounts of 20% by volume. The SCC mixtures are shown in the form R*x*, LS*y*, and R*x*LS*y* in which *x* and *y* are the volume percentages of river sand replaced by RHA or LS, respectively.

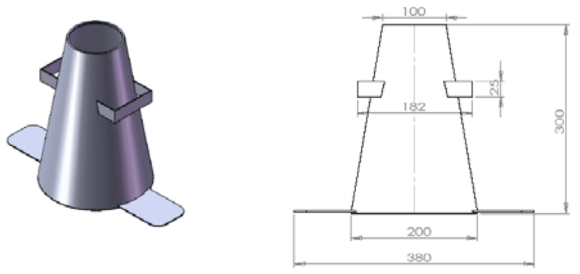
2.3 Testing procedures

The controlled slump flow diameter was maintained at 70 ± 2.5 cm. The unit weight of the freshly prepared SCC was measured as specified in ASTM C29 [13]. The slump flow test was performed with an inverted mold without compaction, in accordance with ASTM C1611 [14]. The reported spread diameters are the averages of 4 measurements. The passing ability was tested with a J-ring, according to the procedure in ASTM C1621 [15]. The filling ability was tested with a V-funnel according to the procedure outlined in EFNARC [16] and as illustrated in Figures. 3(a)-(c).

Hardening properties were determined through the UPV and compressive strength tests with triplicate ∅150 x 300 mm cylinders at each testing, after 1, 7 and 28 days, in accordance with ASTM C597 [17] and ASTM C39 [18].

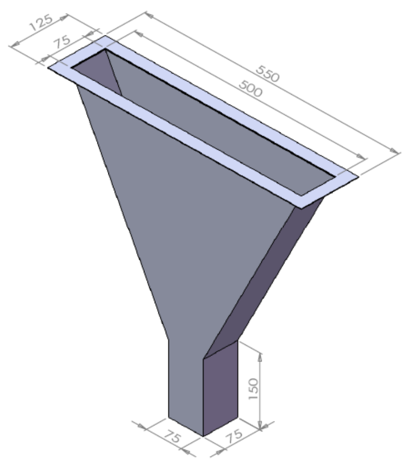
Table 2 Mixture proportions of SCC

SCC Type	Materials [kg/m^3]					
	Cement	Fine aggregate replacement			Coarse aggregate	HRWR [%]
		Sand	Rice husk ash	Limestone powder		
Control	550	813	-	-	708	2
R20	550	650	135	-	708	2
LS20	550	650	-	169	708	2
R5LS15	550	650	34	127	708	2
R10LS10	550	650	67	85	708	2
R15LS5	550	650	101	42	708	2

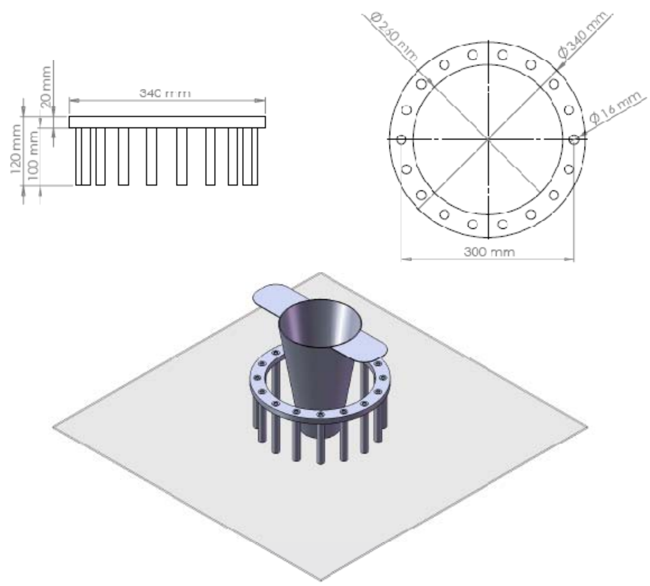


(a) Slump flow test

Dimensions in mm



(c) V-funnel flow test



(b) J-ring test

Figure 3 Workability test apparatus

3. Results and discussion

3.1 Properties of fresh SCC

The properties of fresh and hardened SCC were investigated by replacing the fine aggregate with waste materials, such as RHA and LS powder. The water requirement, unit weight, slump flow, J-ring flow, blocking assessment, and V-funnel test results are listed in Table 3.

Table 3 Fresh properties test results.

Fresh properties	Control	R20	LS20	R5LS15	R10LS10	R15LS5
Slump flow (mm)	700	700	710	680	710	700
J-Ring flow (mm)	680	670	680	660	690	680
Difference flow (mm)	20	30	30	20	20	20
Blocking assessment	None	Minimal	Minimal	None	None	None
T_{50cm} flow (seconds)	6	6	10	7	7	8
V-funnel (seconds)	7	11	10	8	10	14

3.1.1 Water requirement

Figure 4 shows the SCC water/ binder ratios (w/c) that produced controlled slumps of 70 ± 2.5 cm in diameter. To maintain the desired slump flow, SCC containing RHA required greater water content than SCC containing only LS or SCC containing RHA combined with LS. The increased water requirement with increasing amounts of RHA was generally due to the increased specific surface area and high carbon content of RHA. Use of a combination of RHA with LS significantly decreased the water requirement. The mechanism behind this decrease in water demand may be attributed to the absorption of RHA particles by the oppositely charged surfaces of cement particles, which prevents them from flocculating. The LS particles are effectively dispersed and may trap large amounts of water, thereby reducing the water requirement of the system and resulting in the particle packing effect [11].

3.1.2 Unit weight

The unit weight of the SCC decreased with increasing RHA replacement and increased with increasing LS content, as shown in Figure 5. Because the specific gravity of LS (2.76) is larger than that of river sand (2.67)

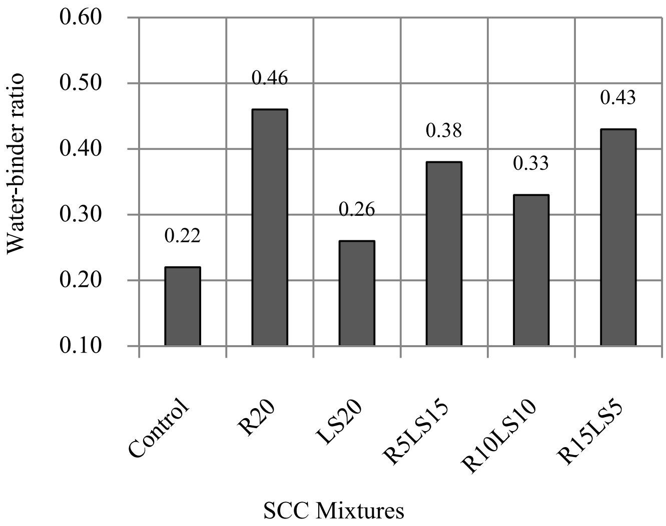


Figure 4 Water requirements

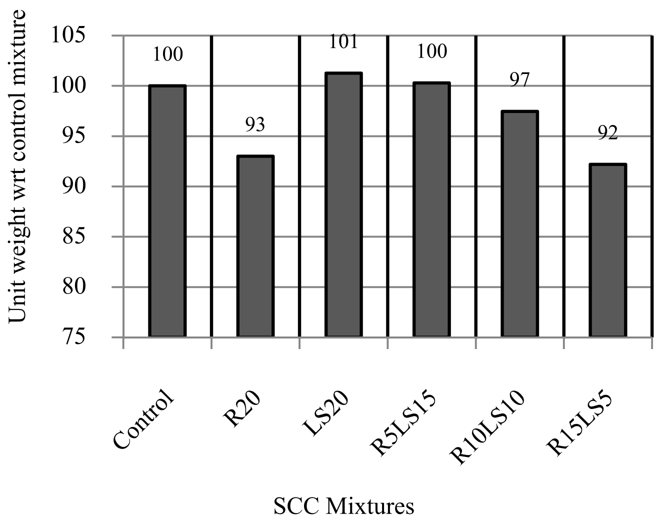


Figure 5 Unit weight of freshly concrete

or RHA (2.2), LS had a strong effect on the unit weight of SCC with RHA and LS replacement.

3.1.3 T_{50cm} slump flow

The slump flow refers to the mean diameter of the concrete mass after the inverted mold has been lifted up. For all of the SCC mixtures tested in the present study, the time required for the slump flow to reach a diameter of 50 cm was within the acceptable range of 3-7 seconds, as per EFNARC guidelines [16]. Thereafter, all of the SCC mixtures exhibited satisfactory slump flows in the range of 70 ± 2.5 cm, as shown in Table 3. The slump flow time ranged from 6 to 10 seconds for SCC mixtures containing combinations of RHA and/or LS, with flow times increasing with increasing amounts of LS. The higher slump flow time may have been due to the increased surface area of RHA, which intensified the viscosity of the paste. Moreover, the effect of the water-binder ratio with RHA replacement reduced the slump flow due to the increased water requirement, as the result of interlocking between the river sand, RHA and LS particles. Conversely, the enhanced viscosity may have reduced the risk of segregation during and after concrete casting [3].

3.1.4 V-funnel test

The V-funnel test is based on the time required for a concrete mixture to flow through a funnel. The results reflect the viscosity and segregation resistance of a concrete mixture. According to EFNARC guidelines, the acceptable range of V-funnel flow times is 8-12 seconds.

In the present study, the V-funnel flow times increased in proportion to the water requirement and replacement level (Table 3). Except for R15LS5, all of the tested mixtures showed V-funnel values that were within the acceptable range. This result indicates that the particles could absorb water, resulting in a highly viscous mixture with reduced bleeding of the cement, aggregate particles, and water. In R15LS5, the V-funnel times were longer due to lower water requirements, compactness, and greater viscosity.

3.1.5 J-ring test and blocking assessment

The J-ring and slump flow tests assess the ability of the SCC to flow under its own weight and to fill the voids completely. The difference between the slump flow and J-ring flow diameter was used to assess the degree of blocking, according to ASTM C1621 [15] and as shown in Table 3. A difference of 0–25 mm [0–1 in.] was defined as “no visible blocking”; difference of 25–50 mm [1–2 in.] was defined as “minimal to noticeable blocking”; and difference >50 mm [>2 in.] was defined as “noticeable to extreme blocking”.

No apparent blocking was observed for the control or any sample containing both RHA and LS. A small degree of blocking was evident in mixtures containing 20% RHA or LS. The J-ring flow results for mixtures containing a combination of RHA and LS showed adequate passing ability and sufficient resistance to segregation around congested reinforcement areas. This finding was due to the combined influence of a decrease in the RHA content and an increase in the water/ powder ratio. A decrease in the amount of river sand by replacement with the finer LS could lead to increased viscosity and, therefore, reduced segregation.

3.2 Properties of hardened SCC

3.2.1 Compressive strength

The average compressive strengths of the SCC samples are presented in Figure 6. The compressive strength consistently increased over the 28-day curing period, varying from 28 to 65 MPa at day 28. The greatest compressive strength was achieved in control SCC mixtures, and the lowest compressive strength was obtained with 20% RHA replacement.

RHA increased the compressive strength of SCC at all curing stages, mostly due to its microfilling ability and pozzolanic activity [10]. The addition of LS also improved the compressive strength of RHA mixtures because the smaller particle sizes were able to fill microvoids within the cement particles. Calcium carbonate, the main component of LS, reacts very little with cement hydrates. Thus, LS may essentially provide a "filler effect" by increasing the compactness of the mixture [19], improving the microstructure in the bulk paste matrix and transition zone, and, subsequently, increasing the compressive strength.

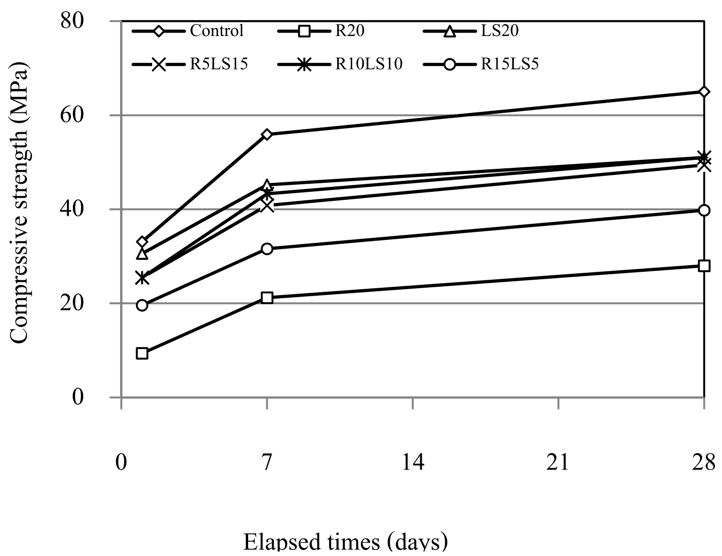


Figure 6 Compressive strength

3.2.2 Ultrasonic pulse velocity

The UPV test is a nondestructive technique used to evaluate the homogeneity of concrete. The velocity of ultrasonic pulses traveling in a solid depends on the density and elastic properties of the tested material. In this study, UPV increased with increasing compressive strength for all of the tested mixtures.

The average UPV values at 1, 7, and 28 days are presented in Figure 7. The UPV values ranged 2.0–4.4 km/s at 28 days. The variations correspond to the degree of densification within the denser internal structure of the SCC mixtures. Higher velocities generally correspond to higher-quality SCC mixtures.

The highest UPV value was achieved with control concrete, and the lowest velocity at all curing ages occurred in samples containing 20% RHA. Addition of LS to the RHA mixtures increased the UPV in SCC samples, via pore refinement and porosity reduction in the bulk paste matrix and transition zone of the concrete. These changes led to a denser pore structure, which in turn contributed to the higher UPV results.

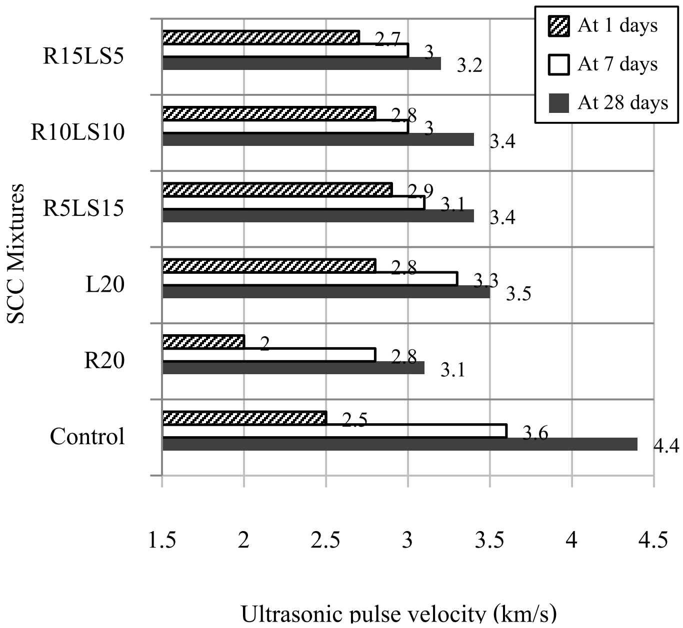


Figure 7 Ultrasonic pulse velocity

4. Conclusions

In the present study, LS filler was used to enhance the properties of RHA that was substituted for the fine aggregate in SCC mixtures. The following conclusions may be made from the data. (1) To maintain a constant flowability, the inclusion of RHA led to a greater increase in the water-binder ratio than did the inclusion of LS in the mixture. The combination of RHA with LS decreased the required water-binder ratio. (2) The unit weight of SCC decreased with increasing RHA content and increased with increasing LS content. Concrete mixtures made of combinations of RHA with LS were lighter than the control and only LS mixtures. (3) When LS was combined with RHA, the J-ring test showed no blocking and the slump flow time was consistently satisfactory, revealing improved workability of the SCC under these conditions. (4) Depending on the replacement levels, the compressive strength decreased with higher water-binder ratios. Thus, suitable replacement of the fine aggregate by RHA and LS can result in early and long-term compressive strength due to the microfilling effect and pozzolanic reaction

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