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Utilization of limestone powder to improve the properties of self-compacting concrete incorporating high volumes of untreated rice husk ash as fine aggregate

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HIGHLIGHTS

- Limestone powder was used to produce self-compacting concrete incorporating RHA.
- The T_{50cm} flow times increased in mixtures containing RHA or RHA and LS.
- Combinations of LS and RHA improved the workability of SCC mixtures.
- The hardened properties of the concretes were progressively improved with addition of LS.

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ABSTRACT

Self-compacting concrete (SCC) is a relatively recent development in the construction industry. It flows under its own weight while remaining homogeneous in composition. We examined the feasibility of using limestone powder (LS) as a modifying agent in self-compacting concrete in which a portion of the fine aggregate was replaced with untreated rice husk ash (RHA). The mixtures were designed to produce a controlled slump flow. The Portland cement content was 550 kg/m^3 for all of the mixtures. The fine aggregate was replaced with up to 100% RHA and LS by volume. The T_{50} slump flow, J-ring flow, blocking assessment, V-funnel, air density, and compressive strength of the SCC mixtures were tested. The fresh properties of the RHA-containing mixtures were improved in mixtures containing less than 60 vol.% RHA. SCCs containing LS exhibited superior hardened properties, and the fresh and hardened properties of SCCs made using RHA were substantially improved when combined with LS. Limestone powder has the potential to improve self-compacting concrete mixtures in which untreated RHA is used as a partial fine aggregate replacement.

1. Introduction

Self-compacting concrete (SCC) has gained wide acceptance in the construction industry since its introduction in 1988 in Japan to address a lack of skilled workers. Its properties are the result of modifications to the composition of ordinary concrete. A comparison of the compositions of SCC and conventional concrete is shown in Fig. 1. SCC flows under its own weight while maintaining resistance to segregation [1,2]. Fresh SCC must be stable to ensure homogeneity and mechanical strength in the finished structure. Several problems may occur in some formulations, including bleeding, settlement, and segregation [3]. Superplasticizers are used to improve the flowability without causing deformation or segregation problems [4]. 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 [5]. Mineral admixtures such as fly ash, limestone powder, blast furnace slag, silica fume, brick powder, kaolinite, bagasse ash, and rice husk ash (RHA) have been used in attempts to improve the properties of SCC [6–12].

Ground RHA is highly pozzolanic and may be used as a supplementary cementitious material in concrete [13,14]. Previous studies have indicated that up to 20% ground RHA may be advantageously blended into the mixture without adversely affecting the strength and durability of the resulting concrete [15]. In addition, it is possible to use residual RHA without grinding by adapting the mixing process to optimize the ash particle size [16]. A preliminary study

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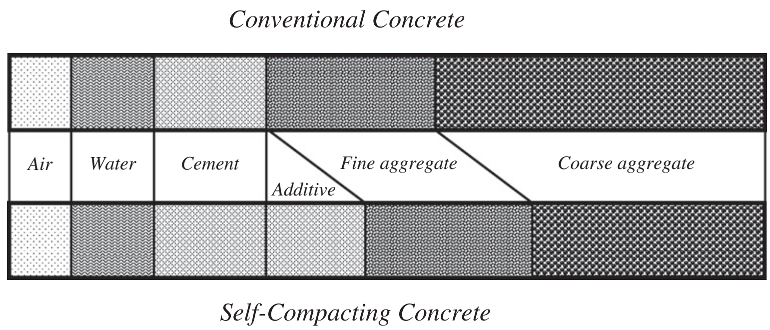

Fig. 1. Comparison of conventional and self-compacting concrete mix proportions [1].

examining the utilization of rice husk ash (RHA) as a cement replacement has demonstrated that incorporation of RHA in SCC decreases the unit weight, flowability, water absorption, total porosity, compressive strength, ultrasonic pulse velocity, and cost [17–20]. Limestone (LS) is a potentially valuable resource produced during stone crushing operations, and is the most common additive for improving the flowability of SCC [21,22]. The addition of limestone reduces the initial and final concrete setting times while increasing the total shrinkage only slightly compared to conventional concrete [23]. The limestone filler also acts as a viscosity enhancer, increasing the workability [24,25].

The objective of this study was to investigate the use of as-received residual RHA as a partial fine aggregate replacement. Satisfactory RHA particle size was 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, particularly for projects near rice production zones and for small contractors.

2. Experimental program

2.1. Materials

The mixtures were prepared using Type 1 Portland cement (OPC) complying with ASTM C150 [26]. The rice husk ash (RHA) was obtained from an electric power plant in Chainat Province, Thailand, and the only treatments prior to use were drying and homogenization. Limestone powder (LS) was obtained from a rock crushing plant located in Saraburi Province, Thailand. The chemical compositions and physical properties of the cement, rice husk ash, and limestone powder are listed in Table 1. The morphologies of the materials were examined using scanning electron microscopy (SEM). Fig. 2 contains SEM images of the materials obtained at approximately 1000× magnification. RHA, OPC, and LS are crystalline materials (Fig. 3). The major phases are cristobalite in RHA and calcite in LS.

A polycarboxylate-based high range water reducing admixture [HRWR] conforming to ASTM C494 [27] standard type F was added to the mixtures at a concentration of 2.0 wt.% of the binder materials. The solids content and specific gravity of the HRWR were 42% and 1.05%.

Table 1
Chemical composition and physical properties of SCC components.

	Type 1 Portland cement	Rice husk ash	Limestone powder
Chemical composition (% by mass)			
Silicon dioxide (SiO_2)	16.39	93.00	8.97
Aluminum oxide (Al_2O_3)	3.85	0.35	1.02
Ferric oxide (Fe_2O_3)	3.48	0.23	0.37
Magnesium oxide (MgO)	0.64	0.41	2.38
Calcium oxide (CaO)	68.48	1.31	46.77
Sodium oxide (Na_2O)	0.06	0.15	0.02
Potassium oxide (K_2O)	0.52	1.61	0.13
Sodium oxide (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

The particle size distributions of the Portland cement and limestone powder were measured using a Malvern Instruments Mastersizer 2000 particle size analyzer. The limestone powder particles were slightly smaller than the Portland cement particles. The fine aggregates included river sand with a fineness modulus of 2.67 and untreated rice husk ash with a fineness modulus of 0.69. The particle size distributions of all aggregate materials conformed to the requirements of ASTM C33 [28] (Fig. 4).

2.2. Mixture proportions

The compositions of the SCC mixtures are listed in Table 2. Several mixtures were prepared containing various fine aggregate replacement amounts. The cement content was 550 kg/m^3 and the coarse aggregate content was 708 kg/m^3 in all mixtures. RHA and LS were used to replace the river sand at levels of 0%, 10%, 20%, 40%, 60%, 80% or 100% by volume. The SCC mixtures were identified using the forms RHAx, LSy, and RHAxLSy, in which x and y are the volume percentages of river sand replaced by RHA or LS.

2.3. Specimen testing

Effective mixing was critical to concrete performance. The concrete was prepared in 35 l batches using a tilting mixer. The addition of superplasticizer was delayed until 1–2 min after the addition of water, resulting in a higher flowability mixture [29]. The procedure is illustrated in Fig. 5.

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 [30] and the air content was measured as specified in ASTM C231 [31]. Slump flow tests were performed using an inverted mold without compaction in accordance with ASTM C1611 [32]. The reported spread diameters are the averages of four measurements. The passing ability was tested using a J-ring according to the procedure in ASTM C1621 [33]. The filling ability was tested using a V-funnel according to the procedure outlined in EFNARC [34] and illustrated in Figs. 6–8. The hardened properties were determined using ultrasonic pulse velocity and compressive strength tests using triplicate cylinders of 150 mm diameter and 300 mm length for each test. Samples were tested after aging for 1, 7, 28, and 91 days in accordance with ASTM C597 [35] and ASTM C39 [36].

2.4. General acceptance criteria

The acceptance criteria for the self compacting concrete mixtures are described in Table 3. The slump flow, T_{50} slump flow, and V-funnel tests were performed according to EFNARC procedures [34]. The J-ring and blocking assessments were adopted from ASTM C1621 [33].

3. Results

3.1. Properties of fresh SCC

The water requirement, unit weight, slump flow, J-ring flow, blocking assessment, V-funnel, and air density test results are listed in Table 4.

3.1.1. Water requirement

The SCC water/binder ratios (w/c) resulting in controlled slumps of 70 ± 2.5 cm diameter are provided in Fig. 9. In order to maintain the desired slump flow, SCC mixtures containing RHA required more water than those containing only LS or a combination of RHA and LS. In general, the water requirement increased with increasing RHA