Research and Development Journal
Volume 25 Issue 4 October-December 2014
Received 24 May 2014 Accepted 29 October 2014

The Engineering Institute of Thailand under H.M. The King's Patronage

COMPRESSIVE STRENGTH AND SULFATE RESISTANCE OF SELF-COMPACTING CONCRETE INCORPORATING AS-RECEIVED RICE HUSK ASH AND LIMESTONE POWDER

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ABSTRACT

In this study, compressive strength and sulfate resistance of self-compacting concrete (SCC) incorporating as-received rice husk ash (RHA) and/or limestone powder (LS) in various replacement levels were investigated. For parametric study, RHA and/or LS were used as a type 1 Portland cement (OPC) replacement material at 0%, 20% and 40% by weight of binder (OPC+RHA+LS). The mixtures were designed based on controlled slump flow in the range of 70 ± 2.5 cm. Flow values and compressive strength of the SCC mixtures were examined. In addition, sulfate resistance of SCC was determined in a 5% sodium sulfate (Na_2SO_4) or a 5% magnesium sulfate ($MgSO_4$) concentration at 1, 7, 28, 90 and 180 days. Results indicated that when increasing percentage replacement of RHA, the expansion and compressive strength loss of SCC increased. However it can be improved by adding LS in the SCC mixtures.

KEYWORDS: Compressive strength, Sulfate resistance, Self-compacting concrete, Rice husk ash, Limestone powder

1. Introduction

Self-compacting concrete (SCC) is an illustration of research in mastering such complex mixtures. The origin of SCCs is associated with the development, at the beginning of the 1980s in Japan, of a design method for fluid concretes. The high seismicity of this geographical region necessitates that structures are highly reinforced with steel. In these much more difficult pouring conditions, compacting the resultant concrete using internal or external vibration is at risk of being insufficient, thereby compromising the building's quality assurance [1]. The method for achieving self-compactability involves not only high deformability of paste or mortar, but also resistance to segregation between coarse aggregate and mortar when the concrete flows through the confined zone of reinforcing bars. This concrete was defined as following (a) limiting the coarse aggregate content, whose energy consumption is particularly intense, to a level lower than normal proportions is effective in avoiding this kind of blockage (b) high deformability can be achieved only by the employment of a superplasticizer (c) keeping the water-powder ratio to be very low value [2]. The high homogeneity of SCC allows it to bond well with reinforcing steel, thereby providing adequate structural performance and durability [3].

Sulfate attack is one of the most important problems concerning the durability of concrete structures. Under the sulfate environment, cement paste undergoes deterioration resulting from expansion, spalling and softening [4]. For the mechanism of sodium sulfate (Na_2SO_4) attack, calcium hydroxide ($Ca(OH)_2$) from the hydration reaction of cement reacted with Na_2SO_4 and transformed to gypsum ($CaSO_4.2H_2O$), leading to the expansion of an outer skin of the specimen. In the case of magnesium sulfate ($MgSO_4$) attack, the reaction between $Ca(OH)_2$ and $MgSO_4$ produced $Mg(OH)_2$, and changed the structure of calcium silicate hydrate (C-S-H) to magnesium silicate hydrate (M-S-H), which is lower in binding capacity and noncementitious material [5]. It is generally recognized that addition of pozzolan such as rice husk ash [4-6] or limestone filler [7-9] reduces the calcium hydroxide in cement paste and improves the permeability of concrete. This helps to increase the resistance of concrete to the attack of sulfate and other harmful solutions.

The ground RHA results in a better sulfate resistance, although at a considerable cost for grinding process. When adapting the mixing process to optimize the ashes particle size. The results are highly dependent of the equipment and mixing cycle adopted. When compared, Concrete without ashes and concrete replacing 15% of the cement by unground RHA achieved similar mechanical and durability properties. It is possible to incorporate unground RHA in conventional concrete [10] and Self-compacting concrete [11]. This study examined the effect of sodium sulfate and magnesium sulfate solutions on the durability of SCC prepared with ternary blends of ordinary Portland cement (OPC), limestone powder (LS), and unground RHA.

2. Experiments

2.1 Materials

The materials used in this study included type 1 Portland cement according to ASTM C150 [12], unground RHA was obtained from thermal power plant and LS was obtained from rock crushing plant. Local river sand with a nominal maximum size of 4.75 mm and crushed limestone rock with having a nominal size of 16.0 mm were used as aggregates. The chemical composition and physical properties were also tabulated in Table 1.

Table 1 Chemical composition and physical properties of SCC components.

Oxide	OPC	RHA	LS
Chemical composition (% by mass)			
Silicon dioxide (SiO_2)	16.39	93.44	8.97
Alumina oxide (Al_2O_3)	3.85	0.21	1.02
Ferric oxide (Fe_2O_3)	3.48	0.18	0.37
Magnesium oxide (MgO)	0.64	0.43	2.38
Calcium oxide (CaO)	68.48	0.76	46.77
Sodium oxide (Na_2O)	0.06	0.05	0.02
Potassium oxide (K_2O)	0.52	1.98	0.13
Sulfur trioxide (SO_3)	4.00	0.16	0.33
SiO_2+Al_2O_3+Fe_2O_3	23.72	93.83	10.36
Physical properties			
Loss on Ignition (% by mass)	1.70	1.27	39.54
Mean Particle size (μm)	23.32	39.34	15.63
Specific gravity	3.15	2.20	2.76
Specific surface area - BET method (cm^2/g)	6100	3700	13000

2.2 Testing procedures

The workability of fresh SCC were evaluated using slump flow, the time required for the concrete spread to a diameter of 50 cm in accordance with ASTM C1611 [13]. The blocking assessment was test by J-ring accordance with ASTM C1621 [14]. The compressive strength of the SCC was determined using 10 x 20 cm cylinder at the age of 1,7 and 28 days as per ASTM C39 [15]. The compressive strength loss due to sulfate attacks, the specimens were cured in saturated lime water until the compressive strength reached at the age of 28 days and then were immersed in 5% sodium sulfate (Na_2SO_4) or 5% magnesium sulfate ($MgSO_4$) at laboratory temperature (23 ± 2 °C), before testing at the age of 1, 7, 28, 90 and 180 days. The expansion due to sulfate attacks was performed in accordance with ASTM C1012 [16] by using 75 × 75 × 285 cm bars. The sulfate solutions were agitated gently for a few minutes at least once a week and occasionally replaced with fresh supplies at least once per month. The pH values of the solutions were monitored and controlled in the range of 6 and 8, by using 0.1 M concentrated sulfuric solutions for adjustment. The measurements of expansion were performed at the age of 1, 7, 28, 90 and 180 days by a shrinkage comparator.

2.3 Mix proportions

The SCC mixtures were adjusted of water/cementitious ratios to produce a controlled slump flow diameter ranged 70 ± 2.5 cm conforming to the EFNARC standard [17]. The replacement levels of RHA and/or LS in OPC (0, 20 and 40%wt. of cementitious materials) as shown in Table 2. The symbols of SCC mixtures were assigned as follows: RHAxLSy;

x is the replacement levels of RHA and y is the replacement levels of LS by weight of OPC. The high range water reducer (HRWR), polycarboxylate-based was added at a concentration of 2.0 wt% of cementitious materials.

Table 2 Mixture proportions of SCC mixes Mixture

Mix	Materials (Kg/m^3)							HRWR (%)	Slump flow (cm)
	Cementitious				Aggregate		w/c		
	Total powder	Cement	Rice husk ash	Limestone powder	Fine	Coarse			
Control	550	550	-	-	813	708	0.26	2.0	70
RHA20	550	440	110	-	813	708	0.42	2.0	70
RHA40	550	330	220	-	813	708	0.57	2.0	68
LS20	550	440	-	110	813	708	0.29	2.0	69
LS40	550	330	-	220	813	708	0.35	2.0	70
RHA10LS10	550	440	55	55	813	708	0.37	2.0	70
RHA20LS20	550	330	110	110	813	708	0.41	2.0	70

3. Results and discussion

3.1 Workability and Compressive strengths

As show in Table 3, the workability of self-compacting concrete will decrease with an increase in cement replacement. For a RHA replacement of 40%, the longest slump flow times, v-funnel flow time and minimal blocking occurred.

Table 3 Workability and compressive strength results.

Mix	Workability					Compressive strength (MPa)		
	Slump flow time (s)	Slump flow (cm)	J-ring flow (cm)	Blocking assessment	V-Funnel flow (s)	1-days	7-days	28-days
Control	4	70	68	No	7	29.3	44.6	61.1
RHA20	6	70	68	No	14	15.3	24.2	33.1
RHA40	7	68	64	Minimal	24	7.6	12.7	21.4
LS20	5	69	69	No	9	29.3	40.7	56.0
LS40	6	70	70	No	14	22.9	34.4	39.5
RHA10LS10	5	70	70	No	12	25.5	36.9	53.5
RHA20LS20	6	70	68	No	17	19.1	28.5	36.0
Criteria [17]	3-7	70±2.5	≥65±2.5		6-12			

This behavior was based on the particle characteristics. Increased porosity resulted in absorbed a large amount of added water [6,10-11], resulting in a highly viscous mixture and related to a lack of cohesion in the mixture. SCC mixtures containing RHA+LS displayed an improved workability due to the finer LS increased the viscosity, packing density and decreased the flow resistance and the segregation [3,7,11]. The compressive strength increased with time ranging from 7.6 to 61.1 MPa as shown in Table 3. The lowest compressive strength results with a RHA replacement 40% due to the pore volume and w/c ratio are increased [4,11]. Use of LS with RHA improved in compressive strength due to the finer particle in can better fill space between the granules [7,11].

3.2 Compressive strength loss due to the sulfate attack

After 180 days of exposure, specimens were tested for compressive strength to determine the percentage of strength loss with reference to the initial strength before exposure to sodium sulfate (Na_2SO_4) and magnesium sulfate ($MgSO_4$) attack of the SCC mixtures are presented in Figure 1a-1b. The results shown increased RHA replacement up to 40%, the strength of concrete is decreased more than 50% due to the high porosity and permeability of concrete [4-6]. However, it seem that the ternary blend concrete exhibits better sulfate attack performance than SCC mixed with RHA replacement in both sodium and magnesium sulfate solution due to LS fines produces a better particle packing, thus resulting in lower porosity and a finer porous structure in SCC [9]. The more pronounced negative effect of magnesium sulfate attack compared to that of sodium sulfate attack in SCC mixtures due to the structure of C-S-H is more prone to be changed to M-S-H, which has low binding ability and results in lower compressive strength [5,9].

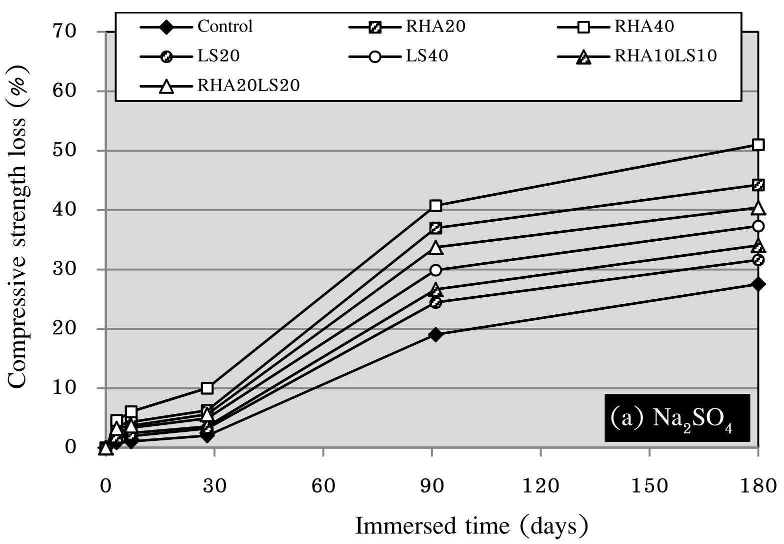

Figure 1 Compressive strength loss of SCC mixtures due to (a) Na_2SO_4 and (b) $MgSO_4$

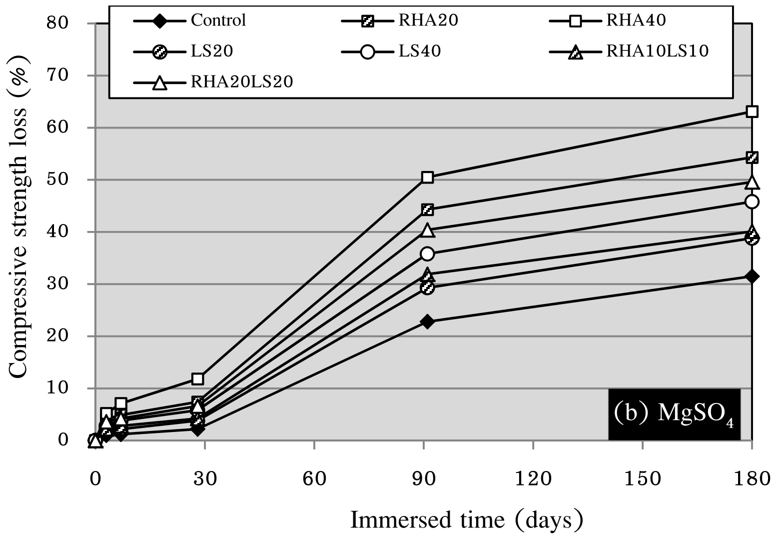

Figure 1 (Cont.) Compressive strength loss of SCC mixtures due to (a) Na_2SO4 and (b) $MgSO_4$

3.3 Expansion due to the sulfate attack

Expansion values of SCC mixtures containing RHA or/and LS in sodium sulfate (Na_2SO_4) and magnesium sulfate ($MgSO_4$) attack are shown in Figure 2a-2b. It was found that the expansion rates are low at the beginning and increases substantially after 28 days of curing. Highest expansion observed in RHA replacement up to 40% due to the higher porosity [5], lower expansion was observed for ternary blend SCC mixed RHA+LS and lowest expansion was observed in 40% are attributed to the reduction of the amount of cement and gypsum formation upon sulfate attack on calcium hydroxide reduced [7-8], respectively.

However, sodium sulfate attack led to more expansion in SCC mixtures than magnesium sulfate attack. These phenomena are largely related to the kinds of products formed by sulfate attack, under magnesium sulfate attack, a main cause of attack is decalcification of C-S-H, Even if ettringite succeeds in forming during magnesium sulfate attack, the product is prone to be unstable in the low alkalinity provided by the brucite formation. On the contrary, in sodium sulfate attack, the expansion associated with the stable of ettringite formation. The sodium hydroxide formed compensates for the loss of alkalinity caused by the consumption of calcium hydroxide [5,9].

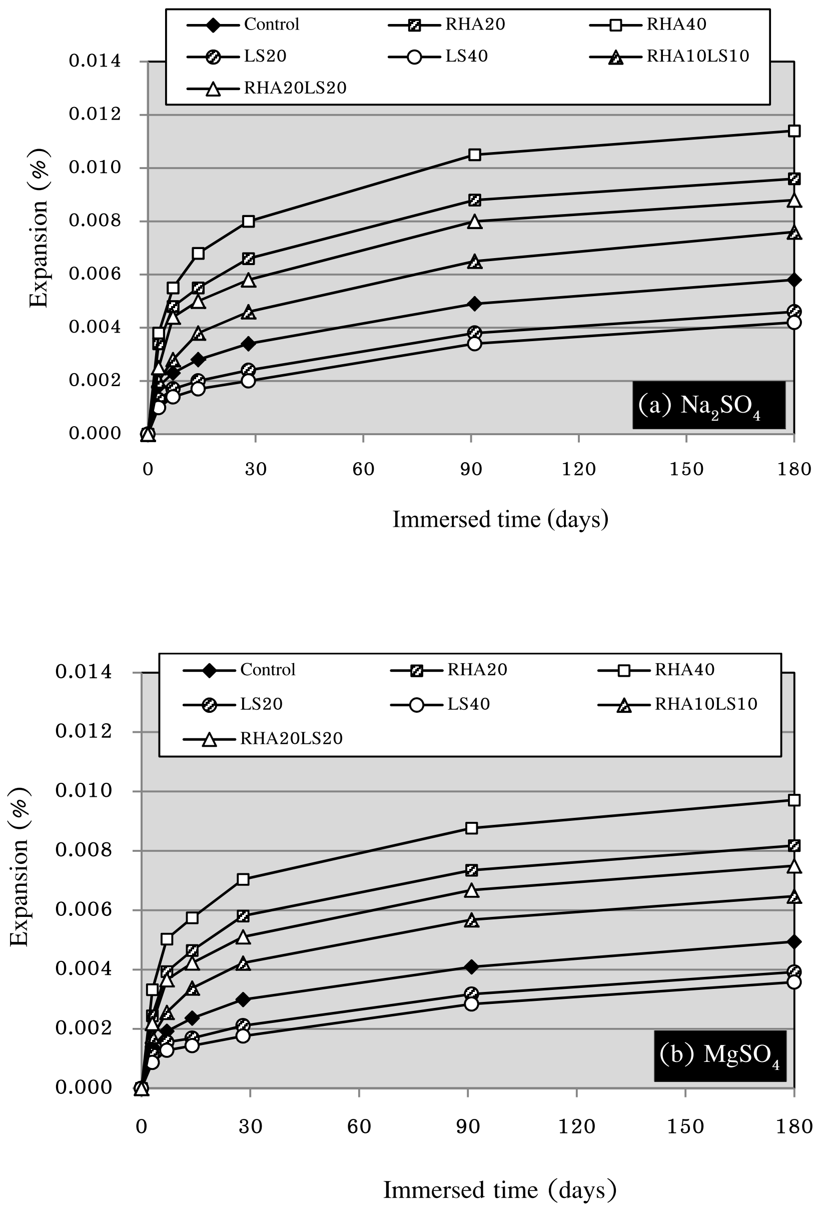

Figure 2 Expansion of SCC mixtures due to (a) Na_2SO_4 and (b) $MgSO_4$

4. Conclusions

For up to 180 days of exposure to sulfate attack, incorporating unground RHA replacing Portland cement has a negative effect in increasing the expansion and compressive strength loss, which it due to the increased porosity. Whereas, the negative effect can be compensate by using LS. A combination of RHA and LS in the SCC mixtures improves its resistance to sulfate attack, decreasing the expansion and compressive strength loss, which due to the finer will act the microfiller in the concrete matrix.

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