บทความวิจัย

INNOVATIVE USE OF FINELY GRADED LIMESTONE FOR IMPROVING THE FRESH PROPERTIES OF SELF - CONSOLIDATING CONCRETE INCORPORATING UNTREATED RICE HUSK ASH

Natt Makul[1*] and Gritsada Sua-iam[2]

[1]Department of Building Technology, Faculty of Industrial Technology,
Phranakhon Rajabhat University, Bangkok, 10220

[2]Department of Civil Engineering, Faculty of Engineering at Rajamangala University of Technology Phra Nakhon,1381 Pibul Songkhram Road, Bangsue, Bangkok 10800

[*]E-mail: shinomomo7@gmail.com

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ABSTRACT

This research examines the potential for improving the properties of high-performance self-compacting concrete (SCC) by incorporating residual-unprocessed rice husk ash waste (RHA) using finely graded limestone (FL) of varying fineness levels (FL1, FL2, and FL3 have mean particle sizes of 4.05 μm, 9.02 μm, and 18.05 μm, respectively). FL was utilized as a type 1 ordinary Portland cement (OPC) substitute at concentrations of 20% and 40% by weight, and RHA was used as a fine aggregate replacement material at a concentration of 20% by weight. The SCC mixtures were designed with a controlled slump flow of 725 ± 25 mm. In this study, the workability in the fresh state and mechanical properties of the blends of OPC and FL were investigated using the slump flow time, V-funnel flow time, flow diameter from the J-ring test. The results show that the use of FL1, FL2, and FL3 can reduce the water content of the powder (OPC and FL). Remarkably, the resulting concretes maintain their slump flow, flow through a V-shaped box, and flow through the obstacles used to assess the J-ring test, thus satisfying the criterion declared by EFNARC. When FL is incorporated at 20 - 40% by weight, its rheological characteristics and compressive strength benefits become sufficiently significant and the inclusion of FL in SCC is both useful and practical.

Keywords: Self-compacting concrete; Rice husk ash; Finely graded limestone; Rheological

Introduction

Accordingly, self-compacting concrete (SCC) can be used to enhance the effectiveness of the process whereby obstructed reinforced steel is cast in situ as structural concrete and completely penetrates any restricted segments without bleeding and segregation. Using present-day concrete technology, SCC requires larger quantities of powder materials, such as ordinary Portland cement (OPC), than conventional concrete. This not only raises the cost of SCC production, but also considerably increases its environmental burden.

To reduce this environmental burden and eliminate concrete waste while recycling byproducts that have potential cementitious material, a number of methods and technologies have been implemented in concrete manufacturing. For more than two decades, potential materials have been combined into SCC as investigators explore mineral admixtures that not only decrease the material and production costs of SCC, but also provide performance benefits. One approach is to recycle certain industrial byproducts.

Numerous industrial byproducts have been considered as mineral admixtures to replace the OPC in the production of SCC. Fly ash (FA) (Atis et al., 2004; Chindaprasirt; 2004; 2007; Felekoglu,et al., 2009) ground granulated blast furnace slag (Binici et al, 2007a; 2007b; Sharmila and Dhinakaran, 2016), and other pozzolanic materials (Kiatikomol et al., 2001; Naik et al., 2013; Kroehong et al., 2011; Ke et al., 2016) are frequently used in SCC. It is reported that the annual worldwide manufacture of FA exceeds 450 million tons (Zhao et al., 2015) and that Thailand produces approximately 3.2 million tons of FA per year (Sua-iam and Makul, 2015). However, there are other potential materials that could be incorporated into SCC, such as un-processed rice husk ash waste (RHA).

Nearly 740 million tons of rice paddy was produced in 2012. On average, 20 - 25% of the rice paddy is husk, yielding an annual total production of approximately 150 million tons (Food and Agriculture Organization of the United Nations, 2014). In rice-producing countries, much of the husk manufactured through the processing of rice is considered a by-product that should be disposed of suitably. Therefore, some investigations have reported the possibility of recycling RHA to produce ultra-high-performance concrete (UHPC) (Rahman et al., 2014; Durgun and Atahan, 2017). For example, Zerbino et al. (2011) reported that concrete without ash and concrete in which 15% of the cement has been replaced by RHA have similar mechanical and durability properties. Although Zerbino et al. (2011) proved that it is possible to use residual RHA in the production of concrete, difficulties arise in terms of how to control the amorphous reactivity according to the fineness characteristic of the unprocessed RHA (Luo et al., 2013; Xu, et al., 2015). Therefore, this study considers a material that overcomes this issue by increasing the fineness and lubricating ability of the paste-aggregate phases in concrete. Namely, very finely powdered is added to increase the applicable range of RHA in concrete.

A number of studies have investigated the use of limestone (Niak et al., 2003; Moon et al., 2017) as a partial replacement for cement (Pera et al, 1999). The current study aims to determine the effectiveness of using byproducts as cement and/or aggregate replacement materials in the production of SCC. This is a state-of-the-art approach to producing SCC and offers a workable way to recycle byproducts. Herein, the use of calcium carbonate powder (FL) as a substitute material for cement is researched to establish its effects on the rheological and mechanical properties of SCC. The principal benefit of utilizing FL as a partial replacement for cement is that FL acts as a filler. Because FL particles have a higher fineness than OPC, they can be used to improve both the workability and cohesiveness of SCC (Pera et al., 1999, Kumar et al., 2017).

Therefore, this research incorporates FL to improve the properties of SCC containing RHA, thus overcoming the crucial problem of using highly porous material to produce concrete. This approach has the economic advantages of minimizing the use of novel materials and reducing the costs associated with dumping coarse byproducts, thereby diminishing the amount of waste consigned to landfill.

Experimental program

Parameters of the study

The main parameters of the investigation were as follows:

1. The types of FL: FL1, FL2, and FL3 had mean particle sizes of 4.05 μm, 9.02 μm, and 18.05 μm, respectively.
2. The amounts of FL used as cement replacements: 20%wt. and 40%wt.
3. The amount of RHA used as fine aggregate replacement: 20%wt.
4. The water–powder materials (OPC + FL) ratio (w/p).

The following parameters were held constant:

1. The total density of the powder material content (OPC + FL) was 550 kg/m^3.
2. The total density of the fine aggregate content (sand + RHA) was 708 kg/m^3 for powder content of 550 kg/m^3.
3. The high-range water-reducing (HRWR) admixture was a polycarboxylic ether (PCE)-based superplasticizer with a recommended dosage of 2.0%wt. of powder materials.

Starting materials

The chemical composition and physical properties of the constituent materials are listed in Table 1.

Type 1 OPC: OPC with a specific gravity of 3.14, complying with ASTM C150 (American Society for Testing and Materials, 2016a).

Residual-unprocessed RHA: A high-SiO_2 RHA that does not comply with ASTM C618 (American Society for Testing and Materials, 2016b) with a specific gravity of 2.20 and a specific surface area of 840 m^2/kg. The RHA was obtained from a biomass thermal power plant in Chainat province, northern Thailand. On average, 20 - 25% of the rice paddy is husk, yielding an annual total production of approximately 150 tons.

Finely graded limestone FL: FL is a main substrate in the production of paper, colors, and plastic. FL1 (mean particle size of 4.05 μm), FL2 (9.02 μm), and FL3 (18.05 μm) each had a specific gravity of 2.71 and specific surface areas of 1,610, 1,540, and 1,420 m^2/kg, respectively, and were not subjected to any additional or previous treatment before incorporation into the solid blends. The alumina waste was obtained from a factory in Lopburi province, central Thailand.

The particle size distributions of the OPC, FL (FL1, FL2, and FL3), and RHA particles were detected using a Malvern Instruments Mastersizer 2,000 analyzer (Enigma Business Park, Grovewood Road, Worcestershire, UK). The specific surface areas of the OPC, FL, and RHA were calculated using the BET method for comparison with the PSD data (OPC: 610 m^2/kg, FL1: 1610 m^2/kg, FL2: 1,540 m^2/kg, FL3: 1,420 m^2/kg, RHA: 840 m^2/kg). The FL particles were finer than the OPC particles, and the RHA particles were coarser than both OPC and FL. The mean particle size diameters in terms of 50% pass particle size ($D_{v,\,50}$) of the OPC, FL1, FL2, FL3, and RHA were 23.32 μm, 4.05 μm, 8.62 μm, 18.05 μm, and 24.32 μm, respectively. In Fig. 1, the sizes of the FL particles are compared with those of gradations of OPC. Finer FL particles have higher packing densities than coarse and irregular OPC and OPC mixed with RHA.

Table 1 Chemical composition and physical properties of OPC, RHA, FL1 (4.05 μm), FL2 (9.02 μm), and FL3 (18.05 μm).

		RHA	FL1 (4.05 μm)	FL2 (9.02 μm)	FL3 (18.05 μm)
SiO_2	16.37 ± 1.25	93.00 ± 2.92	0.17 ± 0.01	0.18 ± 0.02	0.19 ± 0.03
Al_2O_3	3.85 ± 0.28	0.35 ± 0.10	0.06 ± 0.02	0.08 ± 0.01	0.07 ± 0.04
Fe_2O_3	3.48 ± 0.12	0.23 ± 0.04	0.05 ± 0.02	0.07 ± 0.03	0.08 ± 0.01
MgO	0.64 ± 0.05	0.41 ± 0.12	0.32 ± 0.05	0.31 ± 0.04	0.34 ± 0.02
CaO	68.48 ± 3.57	1.31 ± 0.03	66.31 ± 3.55	66.34 ± 3.08	66.28 ± 1.04
Na_2O	0.06 ± 0.01	0.15 ± 0.01	Not detectable	Not detectable	Not detectable
K_2O	0.52 ± 0.06	1.61 ± 0.21	Not detectable	Not detectable	Not detectable
SO_3	4.00 ± 0.42	0.03 ± 0.01	0.02 ± 0.02	0.01 ± 0.01	0.02 ± 0.03
Loss on Ignition	1.70 ± 0.05	1.90 ± 0.01	42.44 ± 2.21	42.53 ± 2.33	42.22 ± 2.04
Physical properties					
Particle size $D_{v,50}$ (μm)	23.32 ± 1.34	24.32 ± 1.79	3.95 ± 1.04	8.62 ± 1.21	16.51 ± 2.64
Specific gravity	3.20 ± 0.07	2.20 ± 0.04	2.71 ± 0.03	2.71 ± 0.06	2.71 ± 0.05
Specific surface area (m^2/kg)	610 ± 13.22	840 ± 17.11	1610 ± 2.14	1540 ± 3.55	1420 ± 6.04

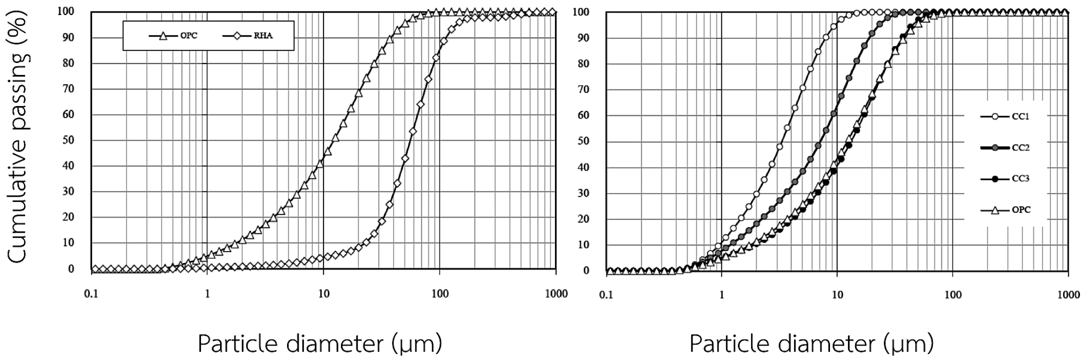

Fig. 1 Particle size distributions of OPC, RHA, and FL plotted using semi-logarithmic scale.

To comprehend the potential influences of different FL size and inert admixtures on the time-dependent viscosity, it is important to describe the micro-shape, surface morphology, angularity, and particle size distribution of the powders (Felekoğlu et al., 2006). For this determination, the surface texture of the OPC, FL, and RHA was examined using a scanning electron microscope (SEM) with 1000x magnification. To demonstrate the surface texture of single particles, SEM morphologies for particles of OPC, FL, and RHA are shown in Fig. 2. As is clear from these images, the OPC particles have no smooth surfaces and are irregularly shaped, and the FL particles are mostly rough and irregular. Furthermore, the RHA particles are coarse-grained with smoother, highly porous surfaces.

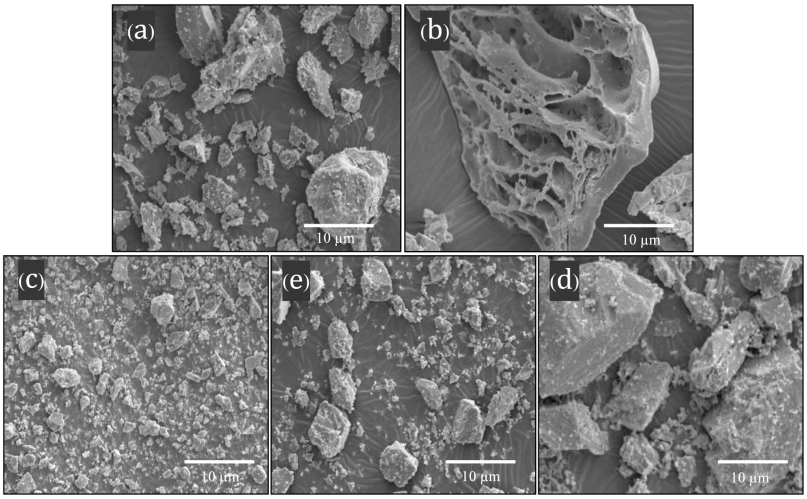

Fig. 2 Scanning electron micrographs (1000×) of (a) OPC, (b) RHA, (c) FL1, (d) FL2, and (e) FL3.

X-ray diffraction (XRD) was used to analyze the compositions of OPC, FL, and RHA, as shown in Fig. 3. In the results, the major compounds in the OPC phases are 35.42% Tri-calcium silicate (Ca_3SiO_5) and 10.42% Brownmillerite, whereas RHA is composed of 20.0% Cristobalite. Moreover, the FL is mostly composed of 29.17% Calcite. The RHA has an amorphous phase of 71.25%, indicating that it may have the potential to react with cement-based systems or to undergo pozzolanic reactions.

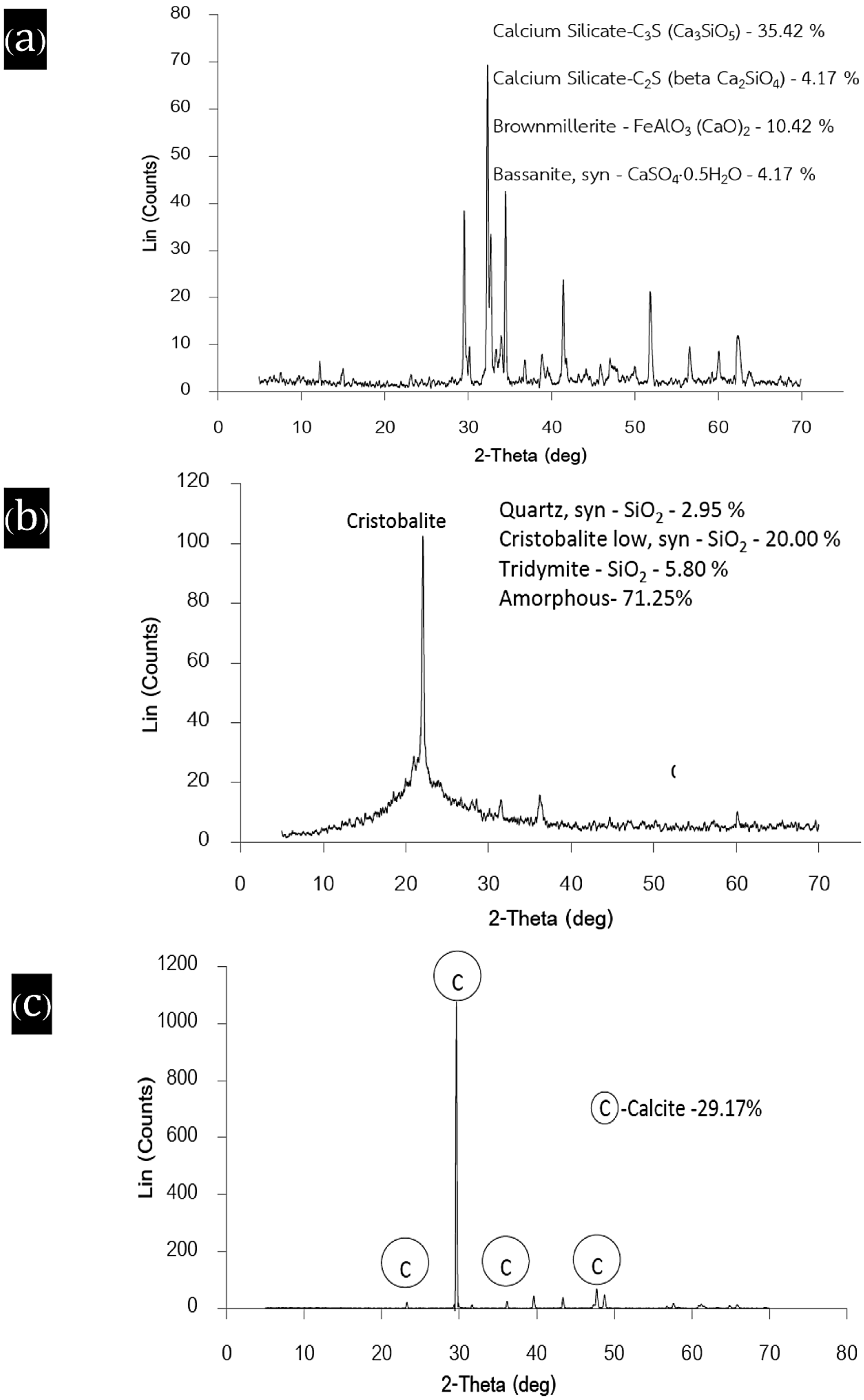

Fig. 3 X-ray diffraction patterns of the materials used: (a) OPC, (b) RHA, and (c) FL.

The chemical admixture was a commercially available PCE-based HRWR. This has an aqueous form with a specific gravity of 1.05 and a solid content of 42.5%, complying with the type G specifications of ASTM C494 (American Society for Testing and Materials, 2016b). This admixture was utilized in all the SCC mixtures to improve and maintain the workability criteria of the SCC.

The gradation of all fine and coarse aggregates used in this investigation complies with ASTM C33 (American Society for Testing and Materials, 2016b). Crushed limestone rock was used as a coarse aggregate with a maximum size of 16 mm, specific gravity of 2.71, fineness modulus (FM) of 7.21, and bulk density of 1550 kg/m^3. Locally available river sand was used as a fine aggregate. This has a maximum size of 4.75 mm, specific gravity of 2.63, FM of 2.73, and bulk density of 1680 kg/m^3.

Mixture proportions

The mixture proportions by weight in kg/m^3 of the starting materials are presented in Table 2. All the SCC mixtures were calculated and designed with a constant total powder material (OPC+FL) density of 550 kg/m^3. The w/p ratio of the mixtures was varied depending on the criteria of the target slump flow at 725 ± 25 mm and the specific HRWR required to obtain the target slump flow. To make the SCC, OPC was replaced with FL at concentrations of 20%wt. and 40%wt. In addition, the fine aggregate (sand) was replaced with RHA at a concentration of 20%wt.

Table 2 Mixture proportions of SCC.

	Materials (kg/m^3)					
SCC Type	OPC	FL	RHA	Sand	Crushed rock	HRWR (%wt.)
550R0	550	0	0	813.0	708.0	2.0
550R20	550	0	162.6	650.4	708.0	2.0
550R0FL1(20)	440	110	0	813.0	708.0	2.0
550R20FL1(20)	440	110	162.6	650.4	708.0	2.0
550R0FL1(40)	330	220	0	813.0	708.0	2.0
550R20FL1(40)	330	220	162.6	650.4	708.0	2.0
550R0FL2(20)	440	110	0	813.0	708.0	2.0
550R20FL2(20)	440	110	162.6	650.4	708.0	2.0
550R0FL2(40)	330	220	0	813.0	708.0	2.0
550R20FL2(40)	330	220	162.6	650.4	708.0	2.0
550R0FL3(20)	440	110	0	813.0	708.0	2.0
550R20FL3(20)	440	110	162.6	650.4	708.0	2.0
550R0FL3(40)	330	220	0	813.0	708.0	2.0
550R20FL3(40)[1]	330	220	162.6	650.4	708.0	2.0

Remarks : [1] XRYFLZ(P) denotes the following: X is the powder material content (OPC + $CaCO_3$ powder (FL)), RY is the percentage replacement by weight of unprocessed-residual rice husk ash, (RHA) content (0% and 20%wt.), FLZ is the size of $CaCO_3$ powder (FL): Size 1 (FL1 (4.05 μm)), size 2 (FL2 (9.02 μm)), and size 3 (FL3 (18.05 μm)) (P) is the percentage replacement by weight of FL content (20% and 40%wt.)

Testing methods

Workability of SCC

The practical requirements for accomplishing a 725 ± 25 mm slump flow with fresh SCC are specified more precisely than those for normal fresh concrete. Workability was measured instantaneously after mixing, which took nearly 10 min. The differences can be summarized based on two main abilities:

1. Resistance to segregation refers to the ability of concrete to remain homogeneous in composition during mixing, transportation, pouring and casting and until setting (Koehler, 2009). This property was tested using a V-funnel (Fig. 4(a)) in accordance with the specified test method declared by the European Federation of

Producers and Applicators of Specialist Products for Structures (EFNARC, 2002).

2. Filling and passing abilities: First filling ability refers to the ability of the concrete to deform under its own weight and to completely fill the formwork while maintaining homogeneity; it is estimated using ASTM C1611 (American Society for Testing and Materials, 2016b) (Fig. 4(b)). Second passing ability refers to the ability of concrete to flow through confined areas without blocking due to the interlocking of aggregate particles. To evaluate the passing ability and blocking behavior of SCC, the concrete was tested with a J-ring (Fig. 4(c)) in accordance with ASTM C1621 (American Society for Testing and Materials, 2016b).

(a) V-funnel flow test (b) Slump flow test (c) J-ring test

Fig. 4 Workability test apparatus and procedures.

Experimental results

Physical properties of fresh SCC

Water requirement in terms of w/p ratio for achieving SCC

The water requirement results in terms of w/p are plotted in Fig. 5. To maintain the required slump flow and to compare the w/p of the control SCC, the mixtures with various amounts of FL required lower w/p ratios than the control SCC. For the mixtures with a powder material content of 550 kg/m^3, the w/p requirements for SCC with FL ranged from 0.15 - 0.22. The lower w/p of SCC is due to the greater specific surface area and finer particle sizes of FL; conversely, the required w/p decreases when the FL particles dissolve in the water, which can increase the viscosity or lubrication of the SCC mixtures to achieve the desired flow slump. Furthermore, the smaller particle size distribution increases the viscosity of the mixture, while the higher particle size distributions increase with decreasing viscosity. For example, FL3 - SCC has a higher w/p than FL1 - SCC.

For the case of SCC containing RHA, the required w/p is higher than that of SCC without RHA because of the high porosity of the RHA particles. However, the SCC mixture with FL achieves higher viscosity than the SCC mixed with RHA.

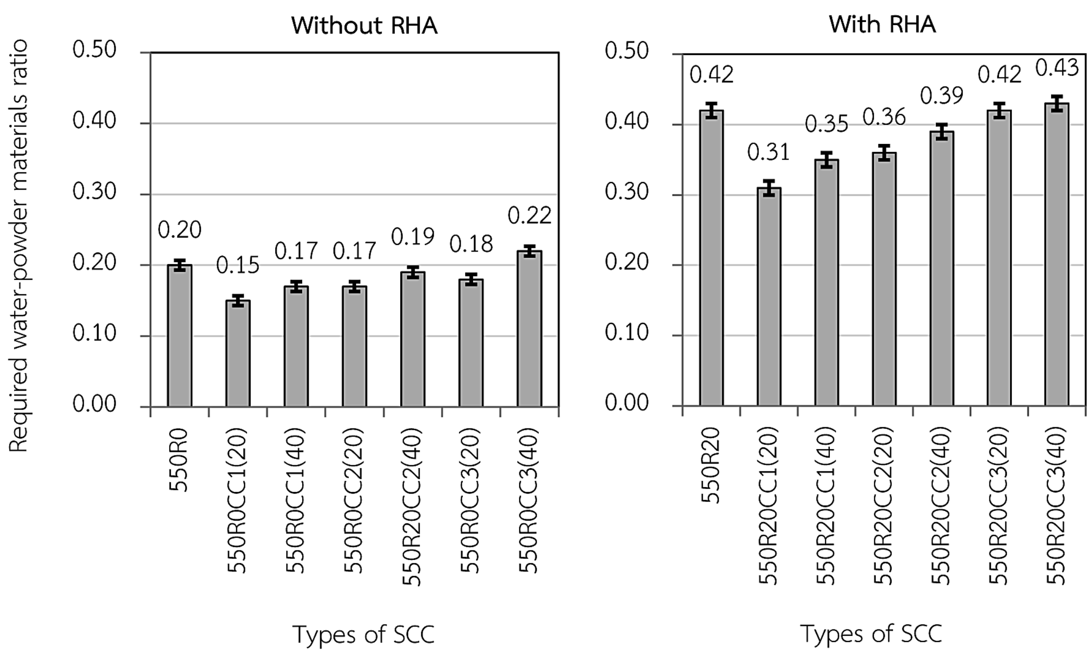

Fig. 5 Water requirements of SCC mixtures.

Unit weight

The wet unit weight of all of the SCC mixtures was evaluated in the fresh state. The results are shown in Fig. 6. Herein, the percentage increase in unit weight is compared with the control SCC mixtures (550R0, 550R20).

The unit weight of the SCC mixtures increased markedly in FL1(20), FL1(40), and FL2(20) and increased with the FL content. For mixtures with powder material densities of 550 kg/m^3, the unit weight of SCC with FL1 of 20% and 40% increased by 1.46% and 0.12%, respectively, and the 20% - FL2 replacement resulted in an increase of 0.45%. This is because FL1 and FL2 (20% FL) have smaller particles than OPC, and can therefore fill the void between the OPC particles. In contrast, the unit weights of SCC with 40% FL replacement and FL3 decreased by 3.25%, 2.75%, and 4.78%, respectively, compared with the control SCC due to the lower specific gravity of FL (2.71). When RHA was added to the mixture, the unit weights of SCC with 20% fine aggregate replacement increased for the 550 kg/m^3 and FL1(20) and FL1(40) cases by 3.93% and 2.02%, respectively. This is because the additional FL can fill the voids between OPC particles (Lone at al., 2002) and the RHA is finer than the sand (Kwan et al., 2014).

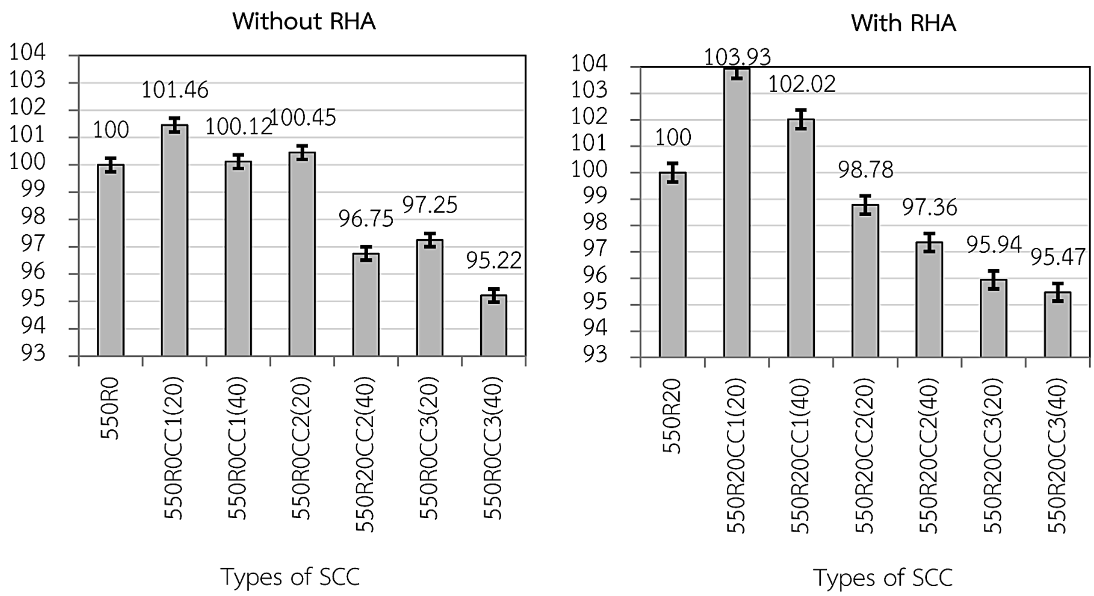

Fig. 6 Unit weight of fresh SCC.

Workability of SCC

According to the EFNARC (2002) and ASTM (American Society for Testing and Materials, 2016b) standards, a concrete mixture can only be classified as SCC if specific requirements for filling ability, passing ability, and segregation resistance are achieved. The workability test results of the fresh SCC, as measured and evaluated by the slump flow time, J-ring flow, V-funnel flow time, and blocking assessment, are presented in Table 3. The results are classified into three groups as stated by the difference between slump flow and J-ring flow: no visible blocking (0 - 25 mm), minimal blocking (25 - 50 mm), and extreme blocking (more than 50 mm), as suggested by ASTM (American Society for Testing and Materials, 2016b).

Filling ability

The slump flow and time to reach a slump flow of 500 mm ($T_{500\ mm}$) indicate the filling ability (Naik et al., 2012), representing the deformation of SCC under its own weight against the friction of the surface with no restraints. In Europe, a range of 725 ± 25 mm is generally used for slump flow testing in most applications. At 700 mm, there is an increased risk of segregation at the beginning of normal concrete placement, but SCC does not suffer from this problem (Santos et al., 2015). The average slump flow of the mixtures was acceptable and indicated good workability (Sua-iam and Makul, 2013). As stated earlier, the SCC mixtures were achieved using varying w/p ratios by maintaining the amount of HRWR.

The slump flow time, which is the time taken by the SCC mixture to reach a diameter of 500 mm, is correlated to the flow rate (Gesoğlu et al., 2012), as stated in the EFNARC guidelines (EFNARC, 2002). All the SCC mixtures achieved acceptable flow times in the range of 3 - 7 s. In this investigation, flow time values were measured using FL1, FL2, and FL3. The effect of the added FL is to enhance the viscosity of the SCC. FL1 (highest fineness) gives a higher viscosity than the coarser mixes (FL2 and FL3).

The flow time values were also observed in mixtures with RHA. The incorporation of FL particles in these mixtures helps to eliminate the effect of mixing RHA (Fung and Kwan, 2014). Similar to the results observed by Sua-iam and Makul (2013), the slump flow time increased in mixtures with high powder (OPC and FL) contents. This could be due to the smooth surface of the FL particles when compared to RHA particles, which would reduce inter-particle friction and increase the viscosity.

Passing ability

The passing ability of the produced SCC mixtures was measured using the J-ring flow; the results are presented in Table 4. The J-ring test is based on the geometry of common concrete applications, namely the minimum spacing between reinforcing bars (Koehler, 2009). The SCC can flow between congested steel bars after the cone is lifted; consequently, the passing ability or blocking behavior of the SCC can be evaluated (Naik et al., 2012). As identified in the ASTM C1621 criteria (American Society for Testing and Materials, 2011b) for the differences in the slump flow and J-ring flow diameters, 0 - 25 mm is defined as no visible blocking, > 25 - 50 mm is defined as minimal to noticeable blocking, and greater than 50 mm is defined as noticeable to extreme blocking. In this study, all the SCC mixtures except those with FL3 at the powder content of 550 kg/m^3 showed no visible blocking or minimal to noticeable blocking. The higher noticeable blocking could be caused by higher viscosity and the agglomeration of the mixtures. As for the filling ability, using RHA in place of sand has no effect on the passing ability of SCC; in fact, passing ability is significantly more affected by the FL. The mean J-ring flow values show a clear trend: the passing ability improves as the OPC and FL content increases, and the mixtures show blocking as the FL3 content increases. This is because, as the paste volume of the SCC mixtures increases, the total volume of the aggregate that must pass through the confined spaces decreases, increasing the inter-particle friction between the fine and coarse aggregates (Koehler, 2009).

Segregation resistance

Segregation resistance plays a significant role in SCC, as poor segregation resistance can cause poor deformability (Sua-iam and Makul, 2015). The V-funnel test measures the time required for SCC to flow down through a funnel, and can be used to estimate the paste viscosity in SCC and resistance to material segregation (Ali and Al-Tersawy, 2012). For the SCC mixtures tested, the segregation resistance was considered satisfactory if the V-funnel time was in the range 8 - 12 s, as identified in the EFNARC (2002) guidelines. The results of this study indicate a clear correlation between the obtained V-funnel flow time results and the variations in the FL replacement levels. The flow time increases as the total powder content and the percentage of fine aggregate replaced by RHA increases. All the SCC mixtures achieved V-funnel values within the acceptable range. The effects of FL materials can be attributed to the shape characteristics and particle fineness of the powder materials. Finer powder materials improve the spread flow values compared with coarser powder (Felekoğlu, 2007). The smooth surface texture of the FL enhances this behavior by contributing to an increase in the amount of free water, which is known to increase workability and cohesiveness (Naik et al., 2012).

Table 3 Slump flow time, V-funnel flow time, and flow diameter from the J-ring test of fresh SCC mixtures.

SCC Type	Slump flow (mm)		$T_{500\ mm}$ slump flow (s)		V-funnel flow time (s)		J-ring test (mm)		Blocking
	Mean	± SD	Mean	± SD	Mean	± SD	Mean	± SD	Assessment[1]
550R0	731.0	± 4.4	5.1	± 1.7	10.2	± 0.5	724.0	± 6.6	No visible blocking
550R0FL1(20)	723.0	± 3.8	5.2	± 1.5	10.2	± 0.4	718.0	± 5.9	No visible blocking
550R0FL1(40)	713.0	± 3.2	7.0	± 1.9	11.3	± 0.6	711.0	± 4.4	No visible blocking
550R0FL2(20)	720.0	± 2.2	4.3	± 1.3	11.1	± 0.1	713.0	± 4.2	No visible blocking
550R20FL2(40)	711.0	± 1.1	6.1	± 1.2	10.1	± 1.1	684.0	± 3.3	Noticeable blocking
550R0FL3(20)	714.0	± 1.3	3.1	± 1.8	9.2	± 0.0	681.0	± 2.1	Noticeable blocking
550R0FL3(40)	708.0	± 0.6	5.3	± 1.1	9.0	± 1.4	678.0	± 1.5	Noticeable blocking
550R20	726.0	± 4.2	6.6	± 1.1	8.1	± 0.5	725.0	± 5.1	No visible blocking
550R20FL1(20)	725.0	± 3.5	6.3	± 1.4	8.4	± 0.4	723.0	± 4.2	No visible blocking
550R20FL1(40)	721.0	± 1.3	7.0	± 1.6	8.9	± 0.9	714.0	± 3.6	No visible blocking
550R20FL2(20)	716.0	± 1.1	5.4	± 1.2	8.3	± 1.1	713.0	± 2.1	No visible blocking
550R20FL2(40)	714.0	± 1.0	7.2	± 1.3	7.6	± 1.5	708.0	± 2.0	No visible blocking
550R20FL3(20)	712.0	± 0.8	4.8	± 1.9	7.2	± 1.0	712.0	± 1.8	No visible blocking
550R20FL3(40)	711.0	± 0.5	6.3	± 1.2	6.3	± 1.2	710.0	± 1.6	No visible blocking

Remarks : [1] For the blocking assessment, the differences in the slump flow and J-ring flow diameters were determined. In this assessment, 0 - 25 mm is defined as no visible blocking, 25 - 50 cm is defined as minimal to noticeable blocking, and greater than 50 mm is defined as noticeable to extreme blocking

Concluding remarks

This investigation has presented a way to improve the rheology, strength, and durability of SCC containing residual-unprocessed RHA using very finely powdered FL. The FL was used as a substitute for OPC at concentrations of 20% and 40%wt., and RHA was used as a fine aggregate replacement material at a concentration of 20%wt. The SCC mixtures were designed with a controlled slump flow of 725 ± 25 mm. The following conclusions can be drawn from the experimental results:

1. To maintain the target flow with a 725 ± 25 mm diameter, the w/p ratio was adjusted. SCC mixtures with/without RHA incorporating FL have a lower w/p than that of the control SCC. Moreover, the unit weight of the SCC with/without RHA

mixtures increased when the FL1(20), FL1(40), and FL2(20) contents increased, and increased when the FL content increased.

2. Considering the workability of SCC, most of the mixtures maintained acceptable flow times in the EFNARC-specified range, while the V-funnel flow results and variations in the FL replacement levels show a general correlation with the increase in FL. The flow time increases as the total powder content and percentage of fine aggregate replaced by RHA increase.

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