Use of High Volume, Untreated Bagasse Ash as a Fine Aggregate Substitute for Preparing Self-Compacting Concrete

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Abstract

We evaluated the suitability of using untreated bagasse ash (BA) as a river sand aggregate in the preparation of self-compacting concrete. Untreated BA was obtained from an electrical power plant, and was received as fractions of 0%, 10%, 20%, 40%, and 60% by volume of river sand. The mixtures were adjusted to maintain a slump flow diameter of 70 ± 2.5 cm. The rheology properties were tested which included filling ability, passing ability, and segregation resistance. Higher fractions of BA were associated with increased water-to-powder ratios and a decrease in unit weight.

1. Introduction

More than twenty years ago, self-compacting concrete (SCC) was proposed by Professor Okamura of Tokyo University to offset a growing shortage of skilled labour. A prototype of SCC was completed in 1988 using commercially available materials, and this prototype was found to perform satisfactorily in three different stages of concrete preparation [1]:

(i) During the Fresh stage: SCC was self-compactable.

(ii) During the Early age stage: SCC did not exhibit initial defects.

(iii) After hardening: SCC afforded protection against external factors.

SCC has also been found to be an innovative concrete that does not require vibration for placing and compaction. Moreover, it is able to flow under its own weight to completely fill formwork and achieve full compaction, even in the presence of congested reinforcement. Consequently, SCC provides a rapid rate of concrete placement, thereby allowing faster construction times and an ease of flow around congested reinforcement. The fluidity and segregation resistance of SCC also ensures a high level of homogeneity, minimal concrete voids, and uniform concrete strength. As a result, SCC provides a superior level of finish and durability to a structure. [2]. Due to the fresh property requirements of SCC, inert and pozzolanic additions are commonly used to improve and maintain the cohesion and segregation resistance of this concrete [2-3].

Bagasse is an important by-product of the sugar cane industry, and most of it is burned to produce steam and electricity in a cogeneration plant. Sugar cane BA is generated from combustion of bagasse, and consists mainly of silica (SiO_2). As a result, BA represents a mineral admixture. BA also acts as a pozzolanic material, and is associated with a lower level of hydration compared to conventional SCC [4]. However, BA is usually produced under uncontrolled burning conditions in boilers of cogeneration processes. Thus, the ash generated may contain black particles that represent carbon. The temperature of

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calcination is also an important parameter for the production of BA with pozzolanic activity [5].

In order to obtain a suitable pozzolanic material for use in concrete [6], controlled grinding of BA is needed to achieve the appropriate fineness and homogeneity. When ground BA constitutes 20% of high-performance concrete, the mechanical response exhibited is equivalent to that of concrete prepared solely from Portland cement [7]. Furthermore, the use of ground BA as a replacement for Portland cement in concrete was found to improve concrete strength, lower water permeability (as well as the corresponding temperature rise), improve rheology at the fresh stage, and increase resistance to the penetration of chloride-ions [6-8].

In this study, the feasibility of using unground BA as a partial fine aggregate in the preparation of SCC was examined in order to eliminate BA grinding time in concrete production.

2. Experimental

2.1 Materials

The starting materials used in this investigation were:

1. Ordinary Type I Portland cement (OPC) complying with ASTM C150 [9] was used.

2. BA was obtained from an electric power plant in the Singburi province of Thailand, and the only treatments prior to use were drying and homogenization.

3. High range water-reducing (HRWR) admixture standard type F complying with ASTM C494 [10] was added to the mixtures at a concentration of 2.0% of the binder material weight.

4. Mixing water discharged into the mixer from the municipal water supply had a pH that ranged from 6 to 8.

5. The fine aggregate was river sand with a nominal maximum size of 4.75 mm. The coarse aggregate was crushed limestone rock with a nominal maximum size of 16.0 mm. Both aggregates conformed to the requirements of ASTM C33 [11].

2.2 Mix proportions

The compositions of the SCC mixtures were designed to maintain a slump flow diameter of 70 $\pm$ 2.5 cm. Untreated BA was received as fractions of 10% (BA10), 20% (BA20), 40% (BA40), and 60% (BA60) by volume of river sand and are listed in Table 1.

2.3 Testing procedures

For each mix, the density and workability of fresh concrete were carried out is given below.

1. The unit weight of freshly-prepared SCC was measured as specified in ASTM C138 [12].

2. The slump flow and slump flow time to reach 50 cm were in accordance with ASTM C1611 [13].

3. The passing ability was tested using a J-ring according to the procedure of ASTM C1621 [14].

4. The time required to flow through a V-funnel was used to determine the filling ability and segregation resistance of the concrete mixtures in accordance with EFNARC [15].

Table 1 Mix Proportions of self-compacting concretes.

Mix No.	Ordinary Portland Cement [kg/m^3]	Replacement [% vol]	Fine Aggregate [kg/m^3]	Bagasse Ash [kg/m^3]	Coarse Aggregate [kg/m^3]	HRWRA[a] [ml/100 kg]
Control	550	-	813	-	708	2000
BA10	550	10	731	72	708	2000
BA20	550	20	650	144	708	2000
BA40	550	40	488	288	708	2000
BA60	550	60	325	432	708	2000

Remark: [a] High range water-reducing admixture standard type F was added to the mixtures at a high concentration of 2.0 wt% of the binder materials. BA, bagasse ash.

3. Results and discussion

3.1 Chemical composition and physical properties

Table 2 lists the chemical composition and physical properties determined for the OPC and BA used in this study. The content of Calcium oxide (CaO) of OPC in this study was 68.48%. The silicon dioxide (SiO_2) and aluminium oxide (Al_2O_3) content were 16.37% and 3.85%, respectively. Loss on ignition (LOI) was 1.7%. Moreover, the specific surface area was 610 cm^2/g and the associated relative specific gravity was 3.20. For BA, the SiO_2 content was 65.26%, the Al_2O_3 was 6.91%, and the iron oxide (Fe_2O_3) content was 3.65%. LOI was 15.34%, resulting in a black color. The specific surface area was 274 cm^2/g and the associated relative specific gravity was 2.35.

Table 2 A comparison of chemical composition and physical properties for OPC and BA.

	OPC	BA
Chemical composition (% by mass)		
Silicon dioxide (SiO_2)	16.37	65.26
Aluminium oxide (Al_2O_3)	3.85	6.91
Iron oxide (Fe_2O_3)	3.48	3.65
Magnesium oxide (MgO)	0.64	1.10
Calcium oxide (CaO)	68.48	4.01
Sodium oxide (Na_2O)	0.06	0.30
Potassium oxide (K_2O)	0.52	1.99
Sulfur trioxide (SO_3)	4.00	-
Physical properties		
Loss on Ignition (% by mass)	1.70	15.34
Particle size distribution (μm)	23.32	107.90
Specific gravity	3.20	2.35
Specific surface area (cm^2/g)	610	274

Particle sizes associated with OPC and BA were determined using a laser granulometer and are shown in Figure 1. The morphology of OPC and BA were also examined using a scanning electron microscope (SEM). The images obtained are shown in Figure 2 (a,b).

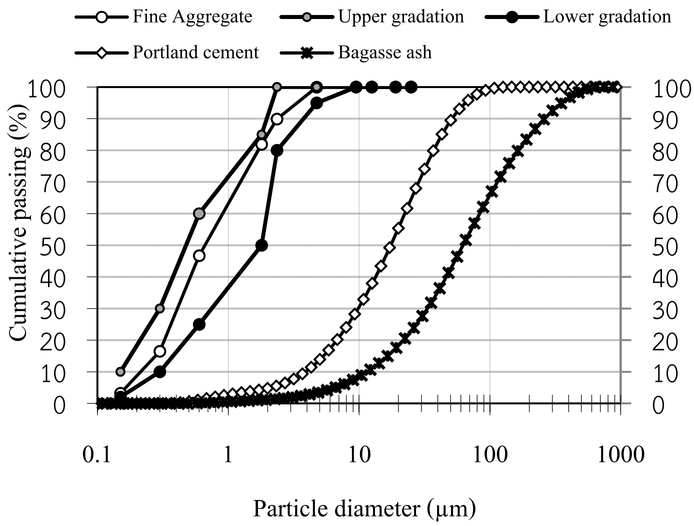
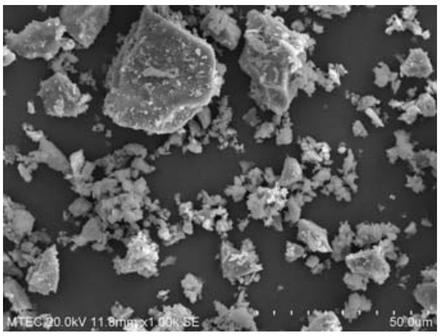
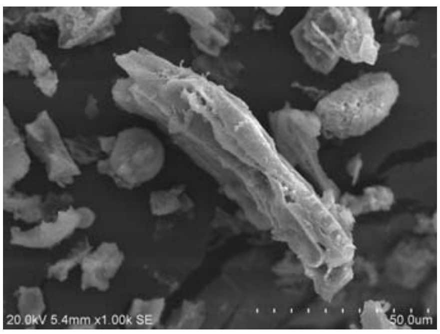


Figure 1 Particle size distribution of Type I Portland cement, bagasse ash and limestone powder



(a) Ordinary type I Portland cement (OPC)



(b) Bagasse ash (BA)

Figure 2 SEM imaging of (a) OPC and (b) BA (Magnification, ~1000X).

3.2 Water requirement

The SCC water-to-powder ratios (w/p) were adjusted to produce controlled slumps with a diameter of 70 ± 2.5 cm (Figure 3). All of the mixes of SCC that contained BA required more water than the control. Furthermore, to maintain the desired slump flow, the amount of water needed for mixes containing BA was found to increase as the proportion of BA increased. This increased water requirement may be due to the porous nature of the bagasse particles, which have a larger surface area and average size, leading to an enhanced absorption of water.

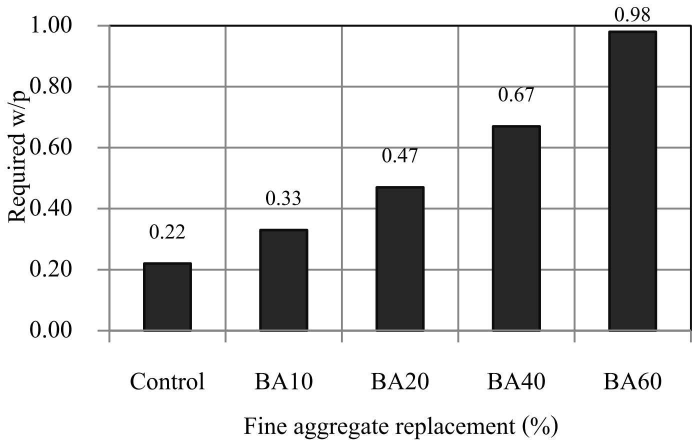


Figure 3 Water requirements for SCC mixtures.

3.3 Unit weight

The unit weight of SCC was observed to decrease when the amount of fine aggregate replacement increased (Figure 4). For example, all SCC mixtures containing BA had lower unit weights than the control. The unit weight of SCC also decreased as the amount of BA replacement increased. The latter is attributed to the lower specific gravity of BA (2.35) compared to river sand (2.67).

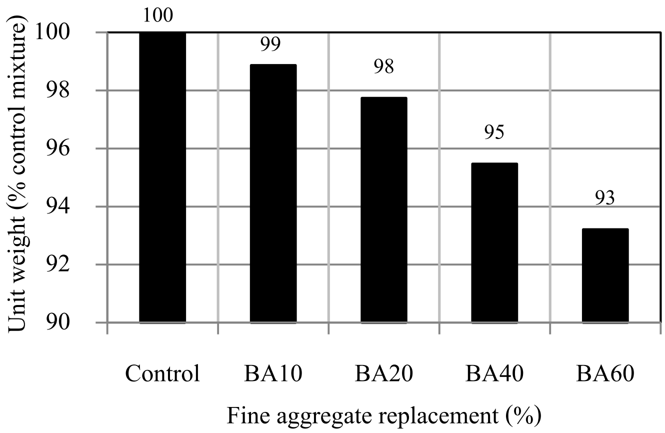


Figure 4 Unit weight of SCC mixtures.

3.4 Slump flow and T_{50}cm slump flow time

Slump flow was controlled by adjusting water-to-powder ratios in order to produce a slump diameter of 70 ± 2.5 cm. The procedure is illustrated in Figure 5, and all of the SCC mixtures produced had a slump flow within the control specification.

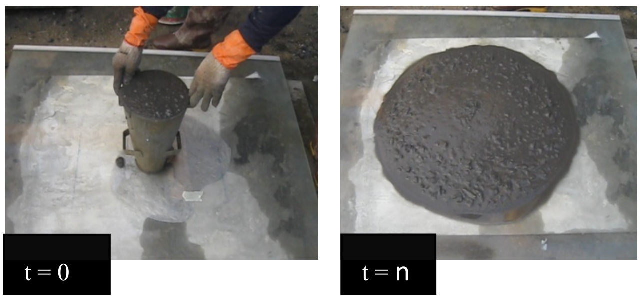


Figure 5 Slump flow time and T_{50}cm slump flow time test performed for BA60.

In Figure 6, the T_{50}cm slump flow times are plotted. The times ranged from 4 to 7 seconds, depending on the proportion of BA present. A slump flow time of 3–7 seconds is acceptable for general applications according to EFNARC [15] guidelines. The SCC mixture containing 60% BHA had the shortest slump flow time, while the mixture containing 10% BA had the longest flow time. Therefore, it appears that a greater volume of BA in the preparation of SCC results in a higher volume of powder material, and this is associated with a lower resistance of flow.

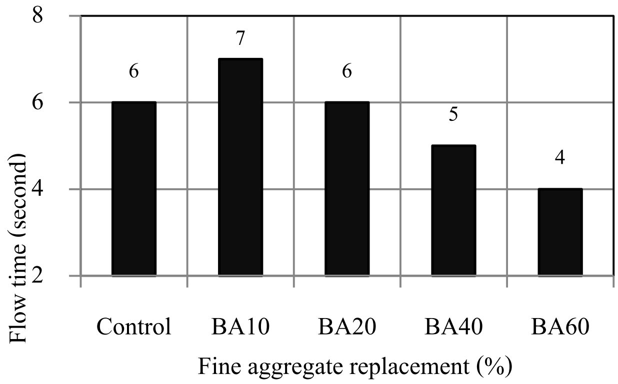


Figure 6 T_{50}cm Slump flow time.

3.5 J – Ring test

Important characteristics of SCC include its passing ability and its segregation resistance, and these are examined using the J-Ring test (Figure 7). This test evaluates the flow behavior of concrete through congested reinforcements.

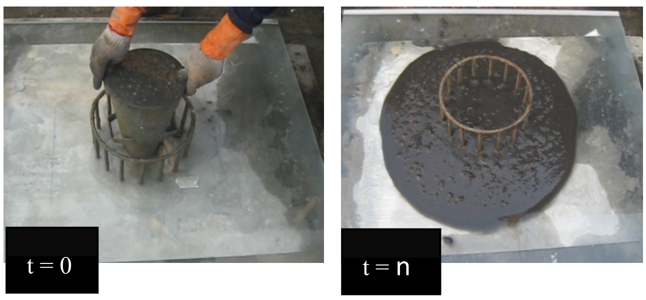


Figure 7 The J – ring test performed for BA60.

In the present study, the test results (Table 3) were found to satisfy the standard requirements (blocking criteria) according to ASTM C1621 [14]. These include, a 0 to 2.5 cm difference to be defined as no visible blocking, a 2.5 to 5.0 cm difference to be defined as minimal to noticeable blocking, and a difference greater than 5.0 cm to be defined as noticeable to extreme blocking. None of the SCC mixtures prepared exhibited apparent or minimal blocking, and none of the blocking ratios were greater than 5 cm. One exception was the mixture containing 60% BA (BA60), which exhibited an extreme degree of blocking and a lack of cohesion. This is possibly due to the large amount of BA and water which were required for the preparation of this mixture.

Table 3 Workability test results.

SCC Type	Slump flow (cm)	J-Ring flow (cm)	Blocking assessment
Control	70	68	None
BA10	70	68	None
BA20	70	67	Minimal
BA40	70	66	Minimal
BA60	70	64	Extreme

3.6 V – funnel flow time

The total time needed for each SCC mixture to pass through the V-funnel shown in Fig. 8 was measured. V-funnel flow times varied from 7 to 35 s and depended mainly on the percentage of BA present, as shown in Figure 9. A V-funnel flow time of 6-12 seconds is the standard EFNARC [15] requirement. In the present study, the flow time increased as the percentage of BA increased. For example, the mixture containing 60% BA had the longest flow time. A long V-funnel time also indicates a relatively high viscosity. Accordingly, BA has been shown to absorb a large amount of water, and this is consistent with the highly viscous mix observed for BA60.

Figure 8 V – funnel flow time test for BA60.

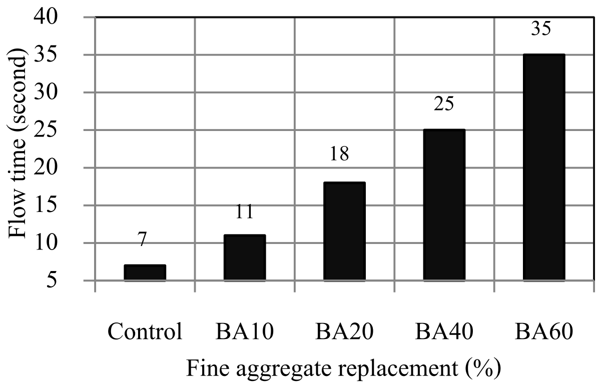


Figure 9 V-funnel flow time.

3.7 The relationship between flowability

To evaluate the material segregation resistance ability of SCC mixtures under fresh conditions, the time required to flow through a V-funnel and the time to reach 50 cm of slump flow were plotted in Figure 10.

For all mixes, the time required to reach 50 cm of slump flow satisfied the expected capacity range. However, the time required to flow through the V-funnel was only satisfied for the control cement and the cement mixture containing 10% BA. In contrast, mixes containing > 20% BA did not satisfy the expected level of result. Furthermore, the time required to reach 50 cm of slump flow was found to decrease as the percentage of BA increased. On the other hand, the time required for flow through the V-funnel was found to increase as the percentage of BA increased. Thus, it appears that a relative decrease in fluidity and an increase in viscosity correspond with a proportional increase in BA.

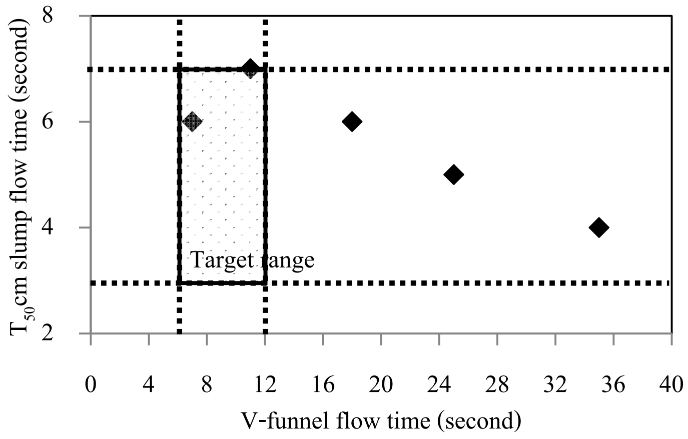


Figure 10 The time required for flow through a V-funnel versus time to reach 50 cm of slump flow are plotted.

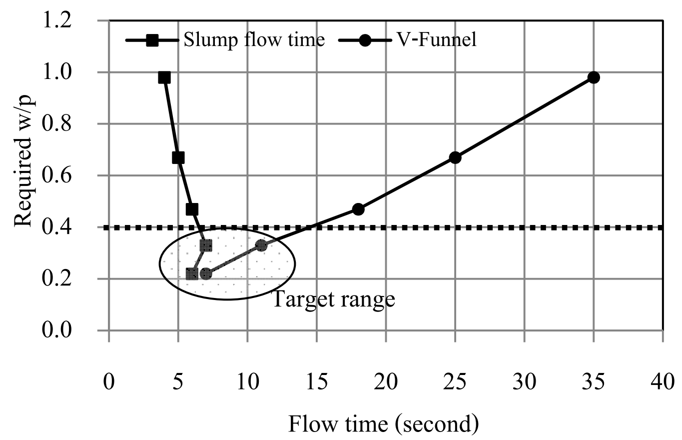


Figure 11 Relationship between water requirement, V-funnel flow time, and time for T_{50}cm slump flow.

The effect of water-to-powder ratio on T_{50}cm slump flow and V-funnel flow time is presented in Figure 11. With the slump flow controlled to produce a slump diameter of 70 ± 2.5 cm, an increase in the proportion of BA did not provide acceptable T_{50}cm slump flow times (e.g., between 3 and 7 s according to the standard EFNARC [15] requirement). Furthermore, the V-funnel times appeared to be more affected by changes in BA content than the T_{50}cm slump flow times. For example, the V-funnel flow times were only acceptable for the control and the BA10 mixture, while SCC preparations containing > 20% BA did not satisfy the expected level of result. Moreover, SCC mixtures having a water-to-powder ratio < 0.40 had a V-funnel flow time less than 12 s. However, a water-to-powder ratio > 0.40 can be achieved if concrete proportions are properly calculated to accommodate SCC criteria.

4. Conclusions

This paper presents a study of the rheology properties of SCC containing unground BA as a fine aggregate replacement. Based on the results obtained, the following conclusions can be made:

1. The water requirement increased as the percentage of BA increased.

2. The unit weight of the SCC mixture produced decreased as the percentage of BA increased.

3. The workability of the SCC mixtures depended primarily on the percentage of BA used. This is consistent with the porous nature of BA particles, whereby a greater surface area and larger average particle size serve to enhance the absorption of water.

4. Only the rheology properties of the of the control and the BA10 mixture were acceptable, while the other mixtures were compromised by a decrease in fluidity and an increase in viscosity relative to the amount of BA present.

5. The optimum water-to-powder ratio for producing SCC ranges from 0.22 to 0.40 by volume. Ratios above and below this range may cause blocking or mixture segregation, respectively.

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