Self-compacting concrete with sugarcane bagasse ash – ground blast furnace slag blended cement: fresh properties

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Abstract. In this investigation, major properties in fresh state of self-compacting concrete (SCC) developed from sugarcane bagasse ash and granulated blast furnace slag as supplementary cementitious materials were examined through an experimental work. There were four mix groups (S0, BA10, BA20, and BA30) containing different cement replacing levels; and totally, 12 SCC mixtures and one control mixture were provided for the test. Fresh properties of the proposed SCC were evaluated through measurement of the density, slump, slump-flow, V-funnel test, T500 slump, Box-test, and setting time. The testing results indicated that replacing either SBA and/or BFS to OPC in SCC mixtures led to lower density, lesser flowability, and longer hardening times.

1. Introduction
When sugarcane bagasse after extraction of economical sugar was burnt for co-generation of heat, about 8-10% ash waste, which known as sugar cane bagasse ash (SBA) was produced [1]. This ash ground in to very fine particles performs potential of pozzolanic characteristics, and beneficially being used to improve concrete properties [2, 3]. In general, as presence of pozzolanic materials such as slag, fly ash, silica fume in cement mixture, the silica (SiO2) commonly being available in these material reacts with calcium hydroxide (Ca(OH)2) released during hydration of Portland cement to additionally form calcium silicate hydrate (C-S-H), leading to improve performance of concrete.

In this investigation, SBA and ground blast furnace slag (BFS) were employed as partial cement substitution materials in developing self-compacting concrete (SCC). The experimental work examined on fresh properties of the SCC such as fresh density, slump, slump flow, T500 and V-funnel flow time, Box-test and the setting time.

2. Methods

2.1 Materials used
- **Cement:** The type I Ordinary Portland cement conformed to the ASTM C150 [4] was used.
- **Sugarcane bagasse ash (SBA):** Raw bagasse ash collected from landfills of a local cogeneration. It was processed with burning at 600-800 °C within one hour before cooling and
grinding to fine particles. The SBA has the Blaine’s fineness of 4010 g/cm$^2$ and specific gravity of 2.02. Chemically, this material was high silica content with 53.2% SiO$_2$, relative high of loss of ignition (LOI, 22.9%), followed by K$_2$O (7.3%) and MgO (2.8%). The sum of main oxides (SiO$_2$ + Al$_2$O$_3$ + CaO) was 63%.

- **Ground blast furnace slag (BFS):** the BFS obtained from a steel factory was used as cement substitution like SBA.
- **Fly ash (FA):** Type F fly ash conforming ASTM C618 [5] was used as filler material which beneficially used to replace VMA in SCC mixtures for enhancement of viscosity [6].

![OPC, SBA, and BFS samples](image)

**Figure 1** Photos of OPC, SBA, and BFS samples used in this study.

Fig. 1 and Table 1 shows the chemical compositions and physical properties of the OPC, SBA, BFS used in this study.

- **Aggregates:** coarse and fine aggregates used in this experiment are crushed limestone and river sand, respectively. These aggregates fully conforms to ASTM C33 [7] for concrete making. The fineness moduli of the coarse and fine aggregates were 6.22 and 2.87, respectively; water absorption were 1.66% for sand and 2.45% for crushed limestone.
- **Super-plasticizer (SP):** A polycarboxylate-based super-plasticizer was used in SCC mixtures.

| Chemical composition (%) by mass | OPC | SBA | BFS |
|---------------------------------|-----|-----|-----|
| Silicon dioxide (SiO$_2$)       | 20.8| 53.2| 36.61|
| Aluminum oxide (Al$_2$O$_3$)    | 4.7 | 6.89| 13.67|
| Ferric oxide (Fe$_2$O$_3$)      | 3.13| 3   | 0.37 |
| Ferric oxide (Fe$_2$O$_3$)      | 3.13| 3   | 0.37 |
| Calcium oxide (CaO)             | 63.2| 3.451| 42.1 |
| Magnesium oxide (MgO)           | 3.33| 2.821| 6.6  |
| Sodium oxide (SO$_3$)           | 2.41| -   | 0.51 |
| Potassium oxide (K$_2$O)        | 0.69| 7.321| -    |
| Sodium oxide (Na$_2$O)          | 0.21| 0.677| -    |
| Loss on ignition (LOI)          | 2.11| 22.9| 0.89 |

| Physical properties             | OPC | SBA | BFS |
|---------------------------------|-----|-----|-----|
| Specific gravity                | 3.15| 2.02| 2.8 |
| Fineness (g/cm$^2$)             | 3530| 4010| 4550|
2.2 Mix-proportions

SCC mixtures in this work were designed according to the densified mixture design algorithm (DMDA) [8]. This design method is appropriate for high performance concrete in which low paste volume is basically required. Cement, slag, fly ash, sugarcane bagasse ash and aggregate were included in the SCC mixtures. Table 2 demonstrated the mix-proportions proposed for this investigation. Totally, there were 13 mixtures belonging four mix groups (i.e., S0, BA10, BA20, and BA30) and one control mixture, containing OPC only.

| No. | Group       | Mix type | Mix ID. | % SBA | % BFS | % OPC |
|-----|-------------|----------|---------|-------|-------|-------|
| 1   | Control     | Single   | BA00-G00| 0     | 0     | 0     |
| 2   | S0- Group   | Binary   | BA10-S00| 10    | 0     | 90    |
| 3   | (0% BFS)    | -        | BA20-S00| 20    | 0     | 80    |
| 4   | -           | -        | BA30-S00| 30    | 0     | 70    |
| 5   | BA10- Group | Ternary  | BA10-S10| 10    | 10    | 80    |
| 6   | (10% SBA)   | -        | BA10-S20| 10    | 20    | 70    |
| 7   | -           | -        | BA10-S30| 10    | 30    | 60    |
| 8   | BA20- Group | Ternary  | BA20-S10| 20    | 10    | 70    |
| 9   | (20% SBA)   | -        | BA20-S20| 20    | 20    | 60    |
| 10  | -           | -        | BA20-S30| 20    | 30    | 50    |
| 11  | BA30- Group | Ternary  | BA30-S10| 30    | 10    | 60    |
| 12  | (30% SBA)   | -        | BA30-S20| 30    | 20    | 50    |
| 13  | -           | -        | BA30-S30| 30    | 30    | 40    |

Notes: Coarse and fine aggregate content were 811 kg/m³ and 828 kg/m³, respectively; binder content (OPC+BA+BFS) was fixed at 434 kg/m³; water/powder of 0.45; SP/binder of 1.4%.

2.3 Testing items for fresh SCC

The fresh SCC was examined through a series of testing procedures following JSCE [9], including fresh density, slump, slump flow, \(T_{500}\) slump time (\(T_{500}\)), V-funnel time (VF) and Box-test. In addition, the initial and final setting time of SCC mixtures was carried out in according to ASTM C403 [10].

3. Primary results and discussion

3.1 Fresh density test

The fresh density ranges from 2070 -2289 kg/m³, as shown in Fig. 2. It was found that density of SCC with blended cement was 1.4%–10% lesser than that of control mix (2299 kg/m³, with OPC only). The mix group BA20 incorporated with BFS had density range to be smaller than those of BA10 and BA30; and the lowest density (2070 kg/m³) was measured on the mixture BA20-S10. It is noticed that low density of the SBA (2.02) and BFS (2.8) in comparing with OPC (3.15) made total mixture volume to increase 1.71%, meanwhile the density decreased about 10% (calculated on mixture BA20-S10). This result would imply concrete made with blended cement contains more porosity.
3.2 Slump and slump flow tests

Fig. 3 show the slump results measured on all SCC mixtures, fully falling in the ranges of 200-300 mm for slump and 550-700 mm for slump flow. According to JSCE [9], these ranges were normally acceptable for many applications. Table 3 presents the limit values for SCC in fresh state, suggested by JSCE. The control mix (BA00-S00) had greatest slump and slump flow. From Fig. 3, presence of either SBA and/or BFS in mixtures led to lesser flowability. The higher amount of cement-replacing materials in binary/ternary system the lower slump/slump flow was. For example, fresh SCC mixture containing 10%, 20%, and 30% SBA had the slump flow decreased by 7%, 9%, and 13% comparing to the control mix, respectively. This behaviour would result from angularity and irregular shapes of cementitious materials, basically enhancing the friction between fine particles making fresh mixture to be harsh. In addition, more natural porosities between SBA particles tending to absorbed some of the mixing water.
Table 3. Limit values for concrete in fresh state proposed by JSCE

| Class of filling ability of concrete                  | 1          | 2          | 3          |
|------------------------------------------------------|------------|------------|------------|
| Construction condition                               | Minimum gap between reinforcement (mm) | 35–60      | 60–200     | ≥ 200      |
|                                                      | Amount of reinforcement (kg/m³)     | ≥ 350      | 100–350    | ≤ 100      |
| Filling high of box-test (mm)                        | ≥ 300      | ≥ 300      | ≥ 300      |
| Flowability                                          | Slump flow (mm)                       | 650–750    | 600–700    | 500–650    |
| Segregation resistance ability                       | Time required to flow through V-funnel (sec) | 10–20      | 7–20       | 7–20       |
|                                                      | Time required to reach 500 mm of slump flow (sec) | 5–25       | 3–15       | 3–15       |

3.3 $T_{500}$ and V-funnel time tests

The $T_{500}$ is defined as the time required for fresh slump flow spreading up to 500 mm after removing the standard slump cone; where V-funnel time (in seconds) performs the flowability and stability of the SCC mixtures, defining as the elapsed time between the moment opening of the bottom outlet and the time when the light becomes visible from the bottom, observed from the top [11]. As seen in Figs. 4-5, the $T_{500}$ and V-funnel time were in duration of 4.31–8.93 sec and 9.03–15.77 sec, respectively. These periods satisfied well for conventional applications, provided by JSCE (see Table 3). Substitution of SBA and/or BFS to OPC made the flow time of fresh concrete to be stably extended. The flow time measured on the largest amount of OPC replacement (BA30-S30) was longest, which was 112% comparing to that of control mix (BA00-S00). Especially, in each SCC mix-group associated with each level of SBA (10%, 20%, and 30%), the $T_{500}$ was shortest at 10% BFS replacement; and it gradually increased as the level of slag increased. Similarly, increase in SBA or BFS caused the significant extension of V-funnel time.

![Figure 4](image_url) Effect of BA/ BFS replacement level on $T_{500}$. 
3.4 Box-test

The Box-test performs the degree of compactability and passing ability through the heavily congested reinforcement under concrete own-weight. Fig. 6 shows the filling height measured from the box-test, ranging from 244–330 mm. JSCE recommends that the height should be 300 mm or greater (Table 3). Hence, only BA10 group (except BA10-S30) and control mix (BA00-S00) achieved the requirement of passing ability. It was obvious that incorporation of both SBA and BFS in SCC mixture led to reduce the filling height.

3.5 Setting time test

Fig. 7 demonstrated the initial and final setting time, varied 550 – 1131 min. and 750 – 1467 min., respectively. The longest hardening times (initial and final) were measured on mixture made of
highest replacement level of minerals (BA30-S30). Incorporation of SBA and BFS caused the retardation of hardening process. For binary mixtures (OPC+SBA), when SBA substituting level varied 10%, 20%, and 30% the setting time increased 35%, 42%, 48% (initial) and 22%, 53%, and 53% (final) in comparing that of control mixture, respectively. Meanwhile, for each mix group in the ternary mixtures (OPC+SBA+BFS), when the slag increased from 10%, 20%, and 30%, the initial setting time were continuously increased 10%, 23%, and 35% (BA10 group), 8%, 24%, and 30% (BA20 group), and 10%, 24%, and 39% (BA30 group), respectively as compared with the corresponding SBA-blended binder mixture (without BFS). Less C3A component originally existing in OPC due to cement replacement and low rate hydration of supplementary cementitious materials owing to contain high calcium silicates could mainly result in the above-mentioned time extension.

![Figure 7 Results of measurement setting time.](image)

4. Highlighted Remarks
Based on the experimental work, some of highlighted remarks could be drawn:

1. Fresh density of SCC mixtures ranges from 2070 - 2289 kg/m$^3$, which is similar to normal concrete. Density of SCC with blended cement was 1.4%–10% lesser than that of control mix.

2. In comparison of control mix, adding SBA and/or BFS in mixtures was apparently resulted in lesser flowability. Angularity and irregular shapes of cementitious materials enhanced the friction between fine particles making fresh mixture to be harsh. Relationship between slump and slump flow can be expressed by a linearly best-fit.

3. Substitution of OPC by SBA and/or BFS made the flow times ($T_{500}$ and $V$-funnel) of fresh concrete to be stably extended.

4. Incorporation of SBA and BFS caused the retardation of hardening process. The longest hardening times (initial and final) were measured on mixture made of highest replacement level of minerals (BA30-S30).

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