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Fresh and hardened properties of self-compacting concrete with sugarcane bagasse ash–slag blended cement

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HIGHLIGHTS

- Using of SBA and BFS can replace OPC in beneficially developing SCC.
- The higher amount of SBA and/or BFS presented in mixture the lesser flowability is.
- Adding SBA and/or BFS in mixture made the flow times to stably extend.
- SCC with 30% SBA and 30% BFS have compressive strength to be comparable to control.
- Presence of SBA and BFS significantly enhanced the resistance of sulfate attack.

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ABSTRACT

This study focuses on combined usage of agro and industrial wastes in developing environment-friendly concrete. Fresh and hardened characteristics of self-compacting concrete (SCC) made of blended cement with sugarcane bagasse ash (SBA, an agro-waste generated during sugar manufacture), granulated blast furnace slag (BFS) and Ordinary Portland cement were examined through an experimental program. Three SCC mix groups (BA10, BA20, and BA30) corresponded with three cement replacing levels of SBA (10%, 20%, and 30%) were developed. For each group, four mixtures associated with four replacement ratios of cement by slag were further employed (0%, 10%, 20%, and 30%). Totally, 12 mixtures incorporating SBA and BFS blended-cement and one reference mix were developed for experiment. Fresh properties of the proposed SCC were evaluated through measurement of the density, slump, slump-flow, V-funnel test, T_{500} slump, Box-test, and setting time. In addition, testing of compressive strength, ultrasonic pulse velocity, sulfate attack, water absorption as well as electrical resistivity were conducted for hardened concrete. The testing results indicated that replacing either SBA and/or BFS to OPC in mixtures led to lesser flowability. Compressive strength of sample made of 30% SBA and 30% BFS substituting to OPC were comparable to that of control after 91 days. Moreover, both of SBA and BFS strongly enhanced sulfate attack resistance; and almost SCC samples had a negligible corrosion rate after 28-day ages.

1. Introduction

Sugarcane bagasse ash (SBA) is an agro-waste generated during the sugar-making processes. Many researchers suggested that SBA ground into very fine particles performs potential of pozzolanic characteristics, beneficially used to improve concrete properties [1–4]. Physically, it is black, highly porous and low density as well as mostly irregular shapes. Raw SBA is usually high moisture content due to absorption of water during disposal in landfills. Moreover, SBA's mineralogy composes of burnt silica-rich fine and un-burnt/partially burnt fibrous carbon-rich (fine and coarse) particles. The former is considered as a pozzolanic material like rice husk ash, fly ash, slag…, whereas the latter is non-pozzolanic. The pozzolanic activity of SBA depends on burning condition, relating to the calcination process. In fact, in condition of air calcination at 600 °C for 3 h with a heating rate of 10 °C/min., SBA performs high behavior due to containing large amount of silica (SiO_2) in amorphous form to be reactive with portlandite [5,6]. However, uncontrolled burning of SBA in high temperature (above 800 °C) leads to negative effect of pozzolanic activity owing to

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phase transitions to low solubility crystalline form of silica content (e.g., α-quartz) [7].

Regarding as binder, the particle sizes contribute a marginal impact on strength pozzolanic index because of enhancing the portlandite consumption and physical effects (filling voids among particles). Cordeiro and Kurtis [8] showed that decrease the d50 resulted in increasing strength indices at 7- and 28 days. When grinding to fine particle with 80% passing through 60 µm sieve and the Blaine specific surface area above 3000 g/cm^2, SBA could be classified as supplementary cementitious material [6,9]. Furthermore, Chusilp et al. [10] confirmed that high LOI content in SBA had no harmful impact on its pozzolanic behavior; and SBA with LOI less than 10% performed well cementitious properties [11].

Self-compacting concrete (SCC) is a special concrete, developed in the late 1980s in Japan and wide-spread over the world there after. In fresh state, SCC is characterized by three highlighted features: (*i*) self-leveling ability without compacting works; (*ii*) self-passing through dense reinforcement gaps, and self-filling corner of formworks; and (*iii*) high fluidity and good resistance of segregation, water bleeding [12]. For SCC mixture, high cement content (400–600 kg/m^3), low water-binder ratio, low coarse aggregate volume as well as a superplasticizer admixture are required. The high viscosity of SCC could be a clearly distinctive point in comparing to conventional vibrated-concrete. This feature can be achieved by adding a viscosity modifying agent (VMA) and/or filler materials (active or inert) to the SCC mixture. The cost of this concrete is expensive due to special requirements of SCC compositions (high cement content and high dosage of chemical admixture). To overcome this, a number of researchers suggested that using mineral additives (by-product materials) to replace OPC and VMA as much as possible. Previous studies reported that presence of mineral by-products (such as fly ash, slag, silica fume, rice husk ask) in SCC mixtures beneficially improved one or more specific properties of concrete in fresh or hardened state [13–16]. In addition, SBA also has been used in replacing the viscosity modifying agent in SCC or filler besides using as a cement replacement as mentioned above [17].

In concrete production, literature review showed that SBA can replace Ordinary Portland cement (OPC) up to 30% by weight of binder. Amin [2] indicated replacement of 20% OPC by SBA in mixture resulted in durability improvement and without any reduction in mechanical properties of hardened concrete. Bahurudeen et al. [18] reported that containing SBA blended-cement (5–25%) was remarkably enhanced concrete performance, such as low heat of hydration, strength improvement, permeability reduction. According to Rerkpiboon et al. [19], compressive strength of concrete with 50% SBA as cementitious replacement was reached at least 90% that of the control concrete after 28 days of curing. It should be emphasized that incorporation of SBA in either mortar or concrete mixture makes the water requirement to increase owing to presence of fibrous particles [3,11]. Recently, several scholars have proposed joint usage of SBA and other by-products (e.g., fly ash, rice husk ash, blast furnace slag, bottom ash and calcium carbide residue –generated from the acetylene gas production [20]) as cement substitution in mixture, which aimed at reducing amount OPC used in cement-based materials. Jiménez-Quero et al. [21] did experiments on mortar mixtures with single ingredient (only OPC was used), binary (SBA or fly ash was used to partially replace OPC) and ternary (SBA, fly ash and OPC) systems. For these mortars, the yield stress linearly increased along with increase in amount of SBA. However, a high concentration of fly ash in binary system or joint effect of SBA and fly ash in ternary one led to potentially decrease the yield stress. Pereira et al. [22] studied the alkali-activated mortar based on SBA and blast furnace slag by using NaOH, KOH, and Na_2SO_4 as activated solutions. As a results, the activated mortar had a better durability performance (in term of resistance to the ammonium chloride, acetic acid, and sodium sulfate environments) than that of plain mortar (OPC only). Cordeiro et al. [23] examined on the characterizations of concretes containing binary and ternary blended-cement with residual rice husk ash and sugarcane bagasse ash. Their results concluded that presence of two ashes effectively improved the rheology (measured via yield stress and plastic viscosity) and compressive strength as well. In short, several positive properties of concrete could be reached when using SBA obtained from agro-industrial processes. However, few studies are available regarding the combined the use of SBA and other pozzolana in concrete.

This investigation is aimed at using both of SBA and BFS as cement-replacing materials in developing SCC with a satisfactory solution to environmental impacts. In the SCC mixtures, SBA and BFS were employed to substitute OPC with different ratios. The fresh and hardened properties of the proposed SCC are systematically examined through an experimental program. This work would contribute a further comprehensive on using agro and industrial wastes in developing environment-friendly concrete.

2. Experimental program

2.1. Materials used

2.1.1. Binders (OPC, SBA, and BFS) and filler (FA)

2.1.1.1. OPC cement. The type I Ordinary Portland cement conformed to the ASTM: C150 [24] had the chemical compositions and physical properties as reported in Tables 1.

2.1.1.2. Sugarcane bagasse ash (SBA). Raw bagasse ash collected from landfills of a local cogeneration. It was black color due to high carbon content (see Fig. 1). The raw material was processed with burning at 600 °C–800 °C within one hour before cooling and grinding to fine particles which were finer than cement (reaching 3% retained on the 325 µm sieve). The SBA used in this test has the Blaine's fineness of 4010 g/cm^2 and specific gravity of 2.02; its physical properties and chemical compositions are shown in Table 1 in comparison with OPC. Images of SEM observation of the obtained SBA were in Fig. 2. Additionally, the X-ray florence analysis results on SBA show that this material was high silica content with 53.2% SiO_2, relative high of loss of ignition (LOI, 22.9%), followed by K_2O (7.3%) and MgO (2.8%). The sum of main oxides ($SiO_2 + Al_2O_3 + CaO$) was 63%.

2.1.1.3. Ground blast furnace slag (BFS). The BFS obtained from a steel factory was used as cement substitution like SBA. The chemical composition and physical properties were tabulated in Table 1.

Table 1
Chemical compositions for OPC, SBA, BFS, and FA used in this study.

	OPC	SBA	BFS	FA
Chemical composition (% by mass)				
Silicon dioxide (SiO_2)	20.8	53.2	36.61	46.01
Aluminum oxide (Al_2O_3)	4.7	6.89	12.92	37.21
Ferric oxide (Fe_2O_3)	3.13	3	0.37	4.69
Calcium oxide (CaO)	63.2	3.451	42.1	2.88
Magnesium oxide (MgO)	3.33	2.821	6.6	1.99
Sodium oxide (SO_3)	2.01	–	0.51	0.71
Potassium oxide (K_2O)	0.51	7.076	–	1.16
Sodium oxide (Na_2O)	0.21	0.662	–	0.22
Loss on ignition (LOI)	2.11	22.9	0.89	5.13
Physical properties				
Specific gravity	3.15	2.02	2.8	2.2
Fineness (g/cm^2)	3530	4010	4550	4050