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Mechanical and durability properties of alkali-activated mortar based on sugarcane bagasse ash and blast furnace slag

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Abstract

Sugarcane bagasse is an agricultural waste which can be transformed, for cementing purposes, into an interesting material by combustion. Specifically, the ash (SBA) obtained by auto-combustion was used for preparing alkali-activated cements by blending blast furnace slag (BFS). SBA had a large amount of quartz; however, it reacted in high alkaline medium. Mixtures of BFS/SBA have been used for preparing alkali-activated mortars, by using NaOH (8 M solution), sodium silicate (8 M solution in Na^+ and SiO_2/Na_2O molar ratio of 0.5) and KOH (8 M solution) as activating solutions. Replacements of 25%, 33% and 50% of BFS by SBA were carried out and compressive strengths in the range 16–51 MPa were obtained after 90 curing days. Microstructural studies demonstrated that the hydration products formed in the activation of BFS are not significantly affected by the presence of SBA in the mixture. The durability of alkali-activated mortars was compared to ordinary Portland cement (OPC) mortar in the following media: hydrochloric acid, acetic acid, ammonium chloride, sodium sulphate and magnesium sulphate. The behaviour of alkali-activated mortars with BFS and BFS/SBA was better than that found for plain OPC mortars, especially in ammonium chloride, acetic acid and sodium sulphate media. After 200 days of testing in ammonium chloride solution, the compressive strength loss for Portland cement mortar was about 83.3%. For the same test conditions, alkali-activated mortars presented a maximum reduction of 48.4%. The presence of SBA in alkali-activated BFS mortars did not produce any serious problems in durability. As a general conclusion, sugarcane bagasse ash (SBA) obtained by auto-combustion showed good cementing properties as a mineral precursor blended with blast furnace slag (BFS) in alkali-activated systems.

Keywords: C. Strength; Alkali activation; Blast furnace slag; Sugarcane bagasse ash; Durability

1. Introduction

The increase in the world's population associated with economic development is generating several problems that are contributing to the global climate change. In the last decades, the world energy supplies have been dominated by fossil fuel (approximately, 80%), which can be associated with environmental problems such as acid rain and greenhouse gas emissions. In the last years, renewable energy sources like wind, solar and biomass have been used in order to promote sustainable development.

Nowadays, biomass represents only about 9–14% of energy sources for industrialised countries and in developing countries, this value is about 20–33% [1]. It is important to state that the energy production from biomass can be considered a renewable energy and this process does not release new CO_2 into the atmosphere: the carbon dioxide is only cycled in the atmosphere.

In Brazil, especially in the São Paulo state, the main agroindustrial activity is associated with sugarcane production

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(approximately, 500 Mt annually). At first, this activity was only associated with the extraction of sugar and ethanol. In the last years, the sugarcane industry has been exploiting the use of sugarcane bagasse as biomass in the production of energy. From this process, about 3 Mt of sugarcane bagasse ash (SBA) is being generated annually.

The main use for this waste material is as a supplementary cementitious material (SCM) in the production of cement, concretes and mortars based on Portland cement [2–5]. According to Fairbairn et al. [2], SBA is an active pozzolanic material which can replace partially the clinker in the cement production significantly reducing the CO_2 emissions into the atmosphere (estimated reduction is about 519.3 kt of CO_2 per year).

Frías et al. [3] assessed the use of three different SBA from the same bagasse waste generated in a sugar factory. The morphology and the pozzolanic reactivity, determined though the fixed lime, of SBA are directly related to the burning temperature of bagasse. In the same way, Cordeiro et al. [4] studied the influence of calcination temperature on the pozzolanic activity of sugarcane bagasse ash. Sugarcane was pre-calcined at 350 °C for three hours and then calcined at 400–800 °C for another three hours. Depending on the calcination temperature, the pozzolanic activity index of SBA was in the range 28–77%.

Nevertheless, it is important to note that the use of SBA as a pozzolanic material is limited to the range 10–35% of Portland cement replacement. Due to this limitation, and thinking about the sustainable development that the reduction on the Portland cement consumption can generate, several studies have been performed in order to produce alternative binders that reduce the raw material and energy consumption and, consequently, the environmental problems associated with the Portland cement production.

The production of alternative binders from the alkaline activation of aluminosilicate materials, the so called alkali-activated binders, is a very interesting alternative for reducing the raw materials consumption and the CO_2 emissions [6]. In the last 20 years, there has been an exponential increase in the number of reports, papers and books related to this issue [7]. Alkali-activated binders are cementitious materials formed by a chemical reaction of an alkaline solution and an amorphous aluminosilicate material that forms materials with binding properties. Usually, alkali-activated binders are produced using fly ash, metakaolin or blast furnace slag as aluminosilicate material [8]. However, as mentioned by Payá et al. [9] in the Handbook of Alkali-Activated Cements, Mortars and Concretes, the development of new precursors is necessary in order to propose this type of binder as cement for the future. Lancellotti et al. [10] assessed the use of incinerator bottom ash in the production of alkali-activated binders using alkaline solutions of concentrated NaOH and waterglass solutions.

In the same way, Payá et al. [9] presented several waste materials that have been investigated in the production of alkali-activated binders, including the use of SBA, in chapter 18 of that book. All of these waste materials can present high degree of valorisation if they are well used for a fixed purpose.

The production of alkali-activated binders is limited to the availability of mineral precursors. In some developing countries it could be interesting to combine selected ashes from agrowastes with typical precursors such as blast furnace slag or fly ash. Sugarcane bagasse ash is one of these options and, it application success will depend on the combustion conditions of sugarcane bagasse, it means, on the physical and chemical properties of SBA.

Castaldelli et al. [11] studied the use of SBA generated in a sugar factory for preparing alkali-activated systems based on binary systems of blast furnace slag (BFS)/SBA. According to the authors, even presenting a high proportion of organic matter (about 25%) and high percentage of impurities (calcite and quartz), SBA from a sugar factory can be an interesting material for producing alkali-activated binders. Mortars cured at 65 °C for 3 and 7 days presented compressive strength values in the range 42.8–53.5 MPa, depending on the proportion of BFS/SCBA (85/15, 75/25 and 60/40). In the same way, mortars cured at room temperature for long curing times presented higher compressive strength than mortars cured at 65 °C and the total porosity of these mortars was also reduced [11]. Recently, Castaldelli et al. [12] presented another paper where the use of fly ash/SBA was reported. In this study, authors calcinated (650 °C during 2 h) the SBA from sugar factory in order to reduce the amount of organic matter and carbon, and using this procedure, it was possible to obtain alkali-activated mortars with good performance.

Moreover, the detailed chemical understanding and the durability properties of these alternative binders are the other main parameters that enable the commercialisation process of alkali-activated binders [13]. In the last years, several papers have reported the durability aspects of alkali-activated binders [14–15]. In general terms, the lower the permeability of concrete, the greater the resistance of concrete to external attacks. Comparing to OPC binders, alkali-activated materials present greater resistance to acidic attack due higher alkalinity of the pore and lower CaO/SiO_2 ratio in the alkali-activated systems [16]. Sulphates attack on alkali-activated binders depends on factors such as the type of activating solution, concentration of alkaline solution and type of cation in the sulphate medium [17–18].

In this paper, studies on reactivity of SBA obtained from auto-combustion conditions are carried out. The valorisation of these ashes in alkali-activated mixtures using blast furnace slag (BFS) is proposed. Selected mixtures replacing part of BFS by SBA obtained by auto-combustion were assessed when sodium hydroxide, sodium silicate and potassium hydroxide solutions were used as activating solutions. In the same way, for selected specimens, durability studies were performed by means of acid attack (hydrochloric acid, acetic acid and ammonium chloride) and sulphate attack (sodium and magnesium sulphates).

2. Experimental section

2.1. Preparation of sugarcane bagasse ash (SBA)

SBA was prepared by auto-combustion [19] of sugarcane bagasse obtained from a sugar industry in Brazil. The process takes 12–14 h for burning 10 kg of biomass. The collected ashes were sieved (2.38 mm) for removing unburned pieces of bagasse. The sieved sample was ground to reduce its fineness.