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Effectiveness of low-concentration acid and solar drying as pre-treatment features for producing pozzolanic sugarcane bagasse ash

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A B S T R A C T

In the production of sustainable concrete, it is quite essential to develop highly reactive silica rich materials to substitute cement. Sugarcane bagasse ash as one of the agricultural based pozzolan gained less popularity due to its relatively low amorphous silica content after incineration process (<50% silica). Therefore, an alternative approach was studied in this research to extract high proportion of amorphous silica from sugarcane bagasse that fulfils the minimum requirement of pozzolanic standard. The process was divided into three stages, which were obtaining optimum pre-treatment variables, obtaining optimum burning variables, and substantiation of pozzolanic feature. Pre-treatment were done to remove all impurities and deleterious material from the ash. It involved soaking of bagasse in different concentrations of hydrochloric acid solution for different interval of time after which it was dried in a dedicated solar drying chamber. Bagasse treated with optimum parameter would then undergo burning process with various temperatures and durations. The produced ash was characterized by determining different oxides composition, particle size analysis, mineralogical characteristics and micro-structure using X-ray fluorescence, nitrogen adsorption, X-ray diffraction, and field emission scanning electron microscope, respectively. The production process was considered environmentally friendly because the ash was produced with optimum parameters (lowest acid concentration and solar drying). The ash obtained using the appropriate pre-treatment and incineration parameters was found to be amorphous, chemically stable, and ultra-fine. Pozzolanic reactivity test also revealed that the ash possessed quite high pozzolanic reactivity index and suitable to be used as cement replacement material. It is evident that the ash enhances the mechanical properties of the mortar specimens tested.

1. Introduction

Global reduction campaign of CO_2 emissions has encouraged further investigations on the use of supplementary cementitious materials for concrete production (Turgut, 2012). The increasing amount of agricultural and industrial waste has attracted many researchers to re-use their wastes as the prospective cement replacement materials (CRM), i.e. fly ash (Topcu et al., 2014; Zhao et al., 2015), rice husk ash (Mutuk et al., 2014; Makul and Sua-iam, 2014), palm oil fuel ash (Rahman et al., 2014; Kanadasan and Razak, 2015), and sugarcane bagasse ash (Sua-iam and Makul, 2013; Li et al., 2015). High pozzolanic reaction reported by previous studies reveals the role of CRM in providing additional reactive silica to form cementitious compounds called Calcium–Silicate–Hydrate (C–S–H) that will increase the mechanical properties of concrete. Sugarcane bagasse (SCB) is among the potential agricultural waste problem contributor and its application in concrete industry has only been lately explored (Ganesan et al., 2007; Chusilp et al., 2009). However, the unique characteristics of sugarcane bagasse have made the disposal process to be slightly challenging. About 60–85% of cellulose and hemicelluloses constituent in SCB are contributing to the high moisture contents inside the bagasse (Abdel-Halim, 2014; Sun et al., 2004). The remaining moisture after juice extraction may lead to the bad odour and unhygienic environment, or heavy smoke issue if open burning is adopted as the primary disposal method.

In the previous studies, most researchers merely concentrate on the effects of Sugarcane Bagasse Ash (SCBA) as a cement

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replacement material in concrete. The extraction of white silica ash via burning process was plainly conducted without considering additional methods to increase the possible proportion of silica that could be extracted. Incineration process of SCB is commonly conducted in an uncontrolled high temperature environment; hence heavy smoke due to the high moisture content from the highly absorptive SCB structure cannot be avoided. Silica ash from this burning process also tends to be less amorphous due to the uncontrolled heating regime. The relative weight proportion of SiO_2 composition was found to be varied below 50% using this direct burning method (Moises, 2011).

Some researchers have also studied the early purification methods to remove impurities and alkali metals coagulated in the bagasse (Feiradon et al., 2014; Gholizadeh et al., 2013) High concentration of acids such as hydrochloric acids, sulphuric acids and tartaric acids (1.0 M–6.0 M) were concluded as the suitable concentration to remove alkali and alkaline metals such as Potassium (K^+), Magnesium (Mg^{2+}), and Calcium (Ca^{2+}) from sugarcane bagasse and other agricultural by-products. This method successfully increased the extraction of SiO_2 up to 80% from SCBA (Patcharin Worathanakul and Akhapon Muangpet, 2009). Nevertheless, the positive result of SiO_2 extraction from those methods has raised other issues, particularly related to the chemical hazard since high concentrations of acid was applied in this method. Therefore this research is proposed to study the optimum method to pre-treat sugarcane bagasse by using low-concentration acid and combined with sunlight heat drying process to promote energy efficiency and eco-friendly approach.

2. Experimental details

Sugarcane bagasse in this research was collected from Perak, Malaysia, which was a by-product from cordial juice industry. Cleaning process of the collected sugarcane bagasse was conducted not more than 24 h after the collection to prevent decomposition of organic substance which may affect the quality of silica in the subsequent extraction process. Sugarcane bagasse was washed in a constantly rotating cylinder for 20 min and dried in a drying chamber afterward. Drying chamber is chosen over electric oven to minimize the carbon footprint and production cost that may arise from the high consumption of electrical energy during the unnecessary operation of electric oven. Drying chamber is designed to collect the heat energy from sunlight and trapped the heat inside the chamber. Material of the chamber is properly selected to minimize the heat loss from the chamber, while at the same time maintain the sunlight penetration into the chamber. Figs. 1 and 2 shows the processing stage in converting raw sugarcane into sugarcane bagasse and the solar drying chamber with its maximum interior temperature of 69.2 °C, respectively.

Subsequent to the 24 h drying process in chamber, dried sugarcane bagasse was pre-treated with low-concentration HCl to remove alkali metals from the bagasse. HCl solutions were prepared at various concentrations of 0.1 M, 0.5 M, and 1.0 M. These

Fig. 2. Solar drying chamber.

concentrations were tested at various soaking periods of 1, 2, 3, 4, 5, and 6 h to obtain the optimum combination of HCl concentration and soaking time that able to extract higher proportion of amorphous silica from sugarcane bagasse. The pre-treated sugarcane bagasse was then dried for 24 h in the drying chamber to remove the excessive moisture and increase its burning efficiency in the incineration process.

Atomic Absorption Spectroscopy (AAS) data was collected using AAS Analyzer ASC-6100 to measure the elements of K (766.5 nm), Mg (285.2 nm), Ca (422.7 nm), Na (589.0 nm), and Fe (248.3 nm) in the soaking-solution residue. Triplicate measurements were conducted for each sample to ensure the soundness of the data with the average of three measurements was taken as the final AAS test result from each sample. Chemical oxide composition of each sample was then determined using S8 Tiger, Bruker X-Ray Fluorescence (XRF) Spectroscopy. At this stage, XRF test was conducted to provide additional justification in determining the optimum treatment combination based on the relative weight proportion of SiO_2 produced if treated sugarcane bagasse is incinerated at particular temperature and period.

The optimum combination of HCl concentration and soaking period from this process was then used as the basis pre-treatment variable in the next burning stage. Investigation on the optimum burning temperature and period was conducted by incinerating the pre-treated SCB in various temperatures (600, 700, and 800 °C) and burning periods (1, 2, and 3 h). SCBA resulted from this incineration process was tested for its mineralogy and chemical oxide

Fig. 1. Processing stage of raw sugarcane into bagasse.

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