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SILICA EXTRACTION AND INCINERATION PROCESS OF SUGARCANE BAGASSE ASH (SCBA) AS POZZOLANIC MATERIALS: A REVIEW

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ABSTRACT

Conventional extraction and incineration process of sugarcane bagasse to extract its reactive silica content has confronted several critical issues, particularly in terms of the amount of reactive silica extracted, energy efficiency, and safety precautions. Based on this evaluation, pretreatment of sugarcane bagasse using acid solution is beneficial, particularly in the removal of alkali metals and increasing the amount of reactive SiO_2. Amorphous SiO_2 from the ashes by the hydration product of calcium hydrate (C-S-H) is completely beneficial in improving performance and durability of concrete. These papers attempts to abridge a review of current literature on the extensive studies that have been undertaken to explore suitable method and pre-treatment to increase the level of silica extraction from SCB with Eco-Friendly approach.

Keywords: sugarcane bagasse, silica, hydrochloric acid, pretreatment, pozzolanic materials.

1. INTRODUCTION

The influence of pozzolanic material in a cementations system is agreed to be substantial, particularly to the development of calcium silicate hydrate framework. Agricultural based pozzolan has been considered as the most feasible option for the sustainability of cementations binder. Rice husk ash, palm oil fuel ash, and sugarcane bagasse ash are among the commonly used agricultural based pozzolans that has been constantly receiving an increasing recognition from researchers due to their abundant availability and reactive silica produced. Environmental concern related to the disposal issue is the major factor that encourages many researchers to further explore the potential utilization of these by-product, since these materials are commonly resistant to natural degradation [1-3].

Transformation of raw by-product into reactive pozzolan is commonly conducted via burning process. Incineration of rice husk will produce ash with 70-80% of reactive SiO_2, 50-60% of SiO_2 in palm oil fuel ash, and 40-50% of SiO_2 in sugarcane bagasse ash [4-7]. Containing the smallest amount of reactive silica, sugarcane bagasse ash has been the least popular source for agricultural pozzolan. It is contrary to its abundant availability where annual sugarcane production could reach 739 million tons in Brazil, followed by 341 million tons in India, 125 million tons in China, and 100 million tons in Thailand (Figure-1) [FAO]. Therefore alternative approach is required to increase the possible amount of SiO_2 could be extracted from sugarcane bagasse, hence make it more attractive as the sustainable source for pozzolanic material.

In the previous researches, most of the studies merely concentrate on the effects of Sugarcane Bagasse Ash (SCBA) as a cement replacement material. Burning process was plainly adopted to transform the bagasse into the ash with only about 50% of SiO_2 was able to be extracted from sugarcane bagasse. Pretreatment process using high concentration acids was introduced to remove alkali and alkaline metal from the bagasse, hence it could increase the amount of SiO_2 extracted. Hydrochloric acid, sulphuric acid, and tartaric acid with various concentrations (1.0 M – 6.0 M) have been studied and functioned efficiently to remove Potassium (K^+), Magnesium (Mg^{2+}), and Calcium (Ca^{2+}) from agricultural by-product. Further extraction on the pretreated specimens was able to increase the amount of SiO_2 up to 80 percent [8]. Nevertheless, the positive result from this pretreatment process has raised secondary issues that are closely related with the utilization of high concentration acid, e.g. safety handling issue and acid waste disposal. Therefore, this paper attempts to review the potential approach in improving the silica extraction with less side issues, particularly concerning the environmental quality.

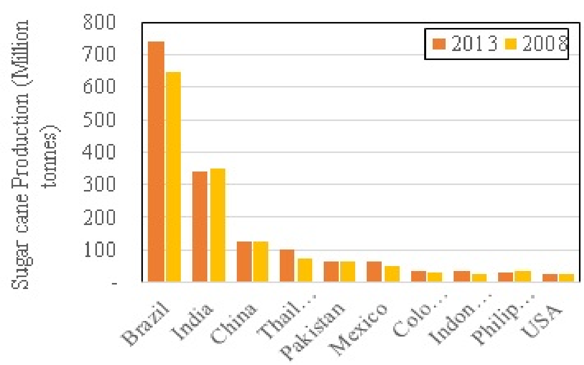

Figure-1. Annual production of sugarcane in the world [FAO].

1.1. Composition of Sugarcane Bagasse

The main constituents of Sugarcane Bagasse are cellulose, hemicelluloses, lignin, ash and wax [9].Cellulose is the most abundant constituent of SCB and also a homo-polysaccharide that composed of β-1,4-

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glucosidic linked glucose monomers[10]. The linear structure of the cellulose chain enables the development of hydrogen bonds into inter- or intramolecular forms. This leads to the aggregation almost 40% glucose chains into crystalline fibrils [10]. Major elements in hemicellulose of SCB are D-xylose, D-glucose, D-mannose, D-galactose and L-arabinos. It has very low degree of polymerization compared to cellulose in which more than 10000 number of glucose unit bound together [11]. A layer called Lignin contributes about 22% to the SCB framework in three-dimensional polymers with three different phenyl-propane precursor monomers. It comprises of p-coumaryl, coniferyl and sinaphyl alcohol. [12] In terms of chemical composition, SCBA is dominantly filled with SiO2 (up to 64.88%), followed by CaO, Al2O3, MgO and Fe2O3 (Table-1).

Table-1. Chemical composition of sugarcane bagasse ash [13].

Chemical composition (%)	*Sugarcane Bagasse Ash*
Silicon Dioxide (SiO_2)	64.88
Aluminum Oxide (Al_2O_3)	6.40
Iron Oxide (Fe_2O_3)	2.63
Calcium Oxide (CaO)	10.69
Magnesium Oxide (MgO)	1.55
(SiO_2) + (Al_2O_3) + (Fe_2O_3)	73.91

1.2. Sugarcane Bagasse ash as pozzolanic materials

Pozzolan is generally described as a reactive material included in a concrete to improve its mechanical properties via pozzolanic reaction. Pozzolan is commonly utilized as a cement replacement material in conventional concrete due to its reactive SiO_2 content and to fulfill the achievement of sustainability agenda. Pozzolanic reaction involves the consumption of amorphous SiO_2 from the ashes by the hydration product of calcium hydrate to form additional calcium silicate hydrate (C-S-H) framework in the cementations system.

Additional formation of this C-S-H framework is beneficial in improving the performance of mechanical strength and durability properties of Portland cement concrete. There are few factors affecting the pozzolanic reactivity of a substance in conventional concrete, e.g. degree of amorphousness, particle fineness, and total amounts of $SiO_2 + Al_2O_3 + Fe_2O_3$ oxide. Higher amount of fine amorphous silica (SiO_2) in a pozzolan will normally increase its pozzolanic reactivity. Sugarcane bagasse ash (SCBA) is an abundant waste from sugar industry, ethanol and ash produced after burning the bagasse as fuel steam for electricity generation. With high amount of silica, alumina and calcium oxide as the main constituents, SCBA is widely used in cement and concrete due to its high pozzolanic reactivity. Figure-2 illustrates the appearance of raw bagasse and bagasse ash after burning process.


(a) (b)

Figure-2. Different states of (a) raw bagasse (b) bagasse ash after combustion.

1.3. Silica extraction method and incineration process of SCB

Previous researchers have investigated the potential applications of SCB as pozzolanic additive in manufacturing composite material or concrete [14-17]. Nevertheless, only few studies that have discussed in detail on the silica extraction method and incineration process particularly are concerning the environmental quality issue. Based on the literatures summarized in Table-2, extraction of silica from the bagasse was conducted simply by burning in high temperature for certain periods, with very less literature discussed on the application of high concentration acid.

Table-2. Silica extraction and burning methods of sugarcane bagasse.

Country/ Year	Silica Extraction Methods	Burning Methods	Observations
Thailand, 2009, [8]	Pre-treatment with high concentration of HCl ,1M and 3M	Controlled burning at different temperatures of 600 ^{0}C, 700 ^{0}C, and 800 ^{0}C and burning period of 1, 2 and 3 hours.	The silica content of 91.57% was achieved from heating of bagasse ash at 600^{0}C for 3 hours under oxygen
India, 2013, [18]	No Pre-treatments	Controlled Burning: Sugarcane calcined through a heating rate of 300 ^{0} C/h then held at 650 ^{0} C/2h and also constant burning temperatures at 500 ^{0} C and 650 ^{0}C	By controlled-burning the bagasse ash at 650^{0}C for 2 hour, the researcher obtained 72% of silica content with some metallic impurities

India, 2013, [5]	No Pre-treatments	Uncontrolled Burning	Bagasse ash collected from sugar plant was brought into a grinding mill for 8 hours before used as CRM. The result of compressive strength with 10% BA, 20% BA and 30% BA shows an increment in strength development with 10% of BA as the optimum limit.
India, 2010, [19]	No Pre-treatments	Uncontrolled Burning	In this research, SCB partially replaced cement with the ratios of 5%, 15% and 25% by weight of cement in concrete. The results show the strength increment along with the increasing dosage of bagasse ash.
Malaysia, 2014, [20]	No Pre-treatments	Uncontrolled Burning	5, 10, 15, 20, 25 and 30% of SCBA was used to replace cement by weight. Inclusion of SCBA in concrete up to 30% significantly improved the microstructure properties and concrete strength

In reference [21] the authors studied the effect of calcinations temperatures of 400, 500, 600, 700 and 800 °C on the pozzolanic activity and loss on ignition (LOI) of the SCBA. The raw bagasse was brought from the sugar mill and burned at different temperatures as mentioned above. They obtained that the SCBA produced at 600 °C for 3 hours (after 3 hours at 350 °C) can possess amorphous silica, low carbon content, high specific surface area and consequently high pozzolanic activity index (PAI) of 77%, while the SCBAs burned at 700 °C and 800 °C had PAIs of 63 and 69%, respectively. The LOIs values for SCBAs burned at 600, 700 and 800 °C were 5.7, 3.0 and 1.3%, respectively, which indicate the complete combustion of char at 800 °C. Meanwhile, in reference [22] the authors also examined the effects of calcinations temperature on the microstructure of sugar cane waste ash (SCWA). The sugar cane bagasse ash SCBA was calcined at 800 and 1000 °C for 20 minutes in an electric furnace. The SCBA that was burned at 800 °C showed less crystallinity than 1000 °C ashes, yet the pozzolanic reactivity was similar for both 800 °C and 1000 °C.

Amongst the pre-treatment and burning condition studies identified between 2007 until 2014, the majority focused on the development of SCB in concrete (50%) by studying the effect of SCB on the compressive strength, workability and pozzolanic reactivity. They analyzed the opportunities for improving while presenting comparative results with existing pozzolanic materials by substituting several percentages of cement with SCBA. 40% of the literatures analyzed the processing method to improve the pozzolanic performance of SCBA and only 10% of the literatures investigated the pre-treatment method by using high concentration of hydrochloric acid. Based on the country of origin, most publications are from India (50%), Thailand (15%), Brazil (15%), Malaysia (15%), and Iran (5%), which also includes the review on the pretreatment of rice husk.

Based on research scopes and methods, most of the literatures present similar objectives, i.e. identifying the effect of SCB as pozzolanic materials in concrete without any pre-treatment process. In this research plot, it is essential to consider the presence of alkali metals in the bagasse since the acid treatment help to dealuminate the bagasse ash and to remove alkali metals to the certain extend [23] [24]. The existence of alkali metals in concrete such as Pottassium (K) and Sodium (Na) may cause the Alkali- Silica Reaction (ASR) problems. ASR is a reaction which occurs over time in concrete between highly alkalis cement paste and reactive silica of aggregate. Therefore, pretreatment process is considered essential to minimize the occurrence of alkali-silica reaction in the application of SCBA as cement replacement material.

Types of chemicals suitable for the pre-treatment of agricultural waste, particularly to pretreat cellulose based material, have been studied by previous researcher. It allows the identification of catalyst (either by acids or enzymes) to penetrate into the cellulose layer hence the reaction may occur more rapidly [25]. The lignin seal surrounding the cellulose microfibril has prevented the contact of catalyst with the crystalline structure of cellulose within which hemicelluloses is intercalated or tapped within these structures. Ladish *et al* suggest that the pretreatment process could break the lignin or wax layer seal, however it requires pretreatment to be carried out above the melting temperature for lignin. Based on this review, pretreatment of sugarcane bagasse using acid solution is beneficial, particularly in the removal of alkali metals and increasing the amount of reactive SiO_2.

2. CONCLUSIONS

Investigation on sugarcane bagasse ash by previous study can be briefly separated into three stages, which are: pre-treatment of sugarcane bagasse; extraction of sugarcane bagasse ash using incineration process, and evaluation of the pozzolanic properties of the ash produced. Soaking the SCB with high concentration of hydrochloric acid is found as essential in order to increase the level of SiO_2 extraction. During pre-treatment process, reaction between acid and water plays the role as a catalyst for facilitating the degradation of lignocelluloses components. However, this available method need to increase its sustainability value hence a more environmentally friendly approach can be achieved without compromising the quality of silica extracted. Incineration duration and temperature in the treatment process of SCBA need to be further explored in order to check for its crystallography pattern in term of degree of amorphousness of sugarcane as pozzolanic materials.

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