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Influence of different processing methods on the pozzolanic performance of sugarcane bagasse ash

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ABSTRACT

Sugarcane bagasse ash is obtained as a by-product from cogeneration combustion boilers in sugar industries. Previous studies have reported that the use of sugarcane bagasse ash as supplementary cementitious material in the concrete can improve its properties. The utilization of bagasse ash has been constrained because of inadequate understanding of the material and lack of suitable processing methodology for use in a large scale. Processing methods significantly influence the pozzolanic activity of any supplementary cementitious material. Proper assessment of pozzolanic activity and processing methodology of bagasse ash were not investigated in earlier research studies. This paper describes a study that involves pozzolanic performance evaluation and microstructural characterization of sugarcane bagasse ash for use as pozzolanic material in concrete. A comprehensive evaluation of pozzolanic activity of sugarcane bagasse ash based on different processing methods including burning, grinding, complete removal of coarse fibrous particles by sieving and combinations of these methods were examined in this study. Suitable processing methodology to attain maximum pozzolanic activity of sugarcane bagasse ash with minimum level of processing is described in this paper.

1. Introduction

Solid wastes from various by-products are used as supplementary cementitious materials to reduce cement content and achieve durable concrete. Sugarcane bagasse ash is obtained as a by-product in enormous quantities from sugar industries. After crushing the processed sugarcane for extraction of juice, the discarded fibrous matter is called bagasse. Bagasse is used as fuel in the cogeneration boiler. The residue after burning, namely bagasse ash, is collected using a bag-house filter.

Most of the supplementary cementitious materials including bagasse ash are industrial by-products and cannot be used directly as pozzolanic material in concrete. Minimum level of processing is needed to achieve the status of pozzolanic material as per standards [1]. Various processing methods have been used in previous research studies to evaluate their effects on the pozzolanic activity of different supplementary cementitious materials including fly ash, silica fume, slag, rice husk ash, and metakaolin. A few notable studies are mentioned here.

Burning process significantly influences the pozzolanic activity of supplementary cementitious materials [2]. Plants ingest orthosilicic acid from ground water, which is later polymerized as amorphous silica in the plant cells [3]. When bagasse is used as fuel in the combustion boiler of cogeneration plant under controlled burning, reactive amorphous silica is formed because of combustion process and it is present in the residual ashes [4]. Chopra et al. [5] found that amorphous form of silica was retained in rice husk ash up to 700 °C controlled burning, and further increase in temperature led to crystallization of silica to crystobalite. Nair et al. [6] studied ^{29}Si MAS NMR spectroscopy patterns for different burnt samples of rice husk ash. Broad peak was observed at −111 ppm along with small peak at −102 ppm for 500 and 700 °C burnt samples. This was attributed to dense silicate network and reactive silanol groups which were responsible for reactivity of the material. In case of the sample burnt at 900 °C and 1100 °C, narrow peaks were observed at −110 ppm and −112 ppm due to presence of crystalline crystobalite and tridymite.

Pozzolanic activity of metakaolin (MK) highly depends on calcination temperature [7]. Kaolin is stable at room temperature. Heating to 600–900 °C leads to dehydroxylation of bound hydroxyl ions and breaks down the long range structure of kaolin [8]. This results in a highly amorphous transition phase and leads to formation of reactive metakaolin. Heating kaolin at high temperature above 550 °C leads to loss of structural OH groups [9]. Another study

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[10] reported that heating above 550 °C caused rearrangement of Si and Al atoms in the kaolin structure and also resulted in the appearance of penta and tetra coordinated Al. Recrystallization of metakaolin is found to occur at about 900 °C and silicon-spinel is formed at 925 °C. When the temperature is above 1400 °C, mullite is generated [11]. Brindley and Nakahira [2] investigated the phase transformation of kaolinite by heating to higher temperature and reported that silicon-spinel and mullite had lesser pozzolanic reactivity. Morat and Comel [12] suggested 700–800 °C calcination for higher pozzolanic activity. Rashad [13] reviewed all the calcination research studies of metakaolin and concluded that optimum duration for calcination varies among different researchers. They suggested that the optimum temperature for kaolin calcination to obtain highly reactive MK was 600 °C for 4 h.

After the burning temperature, particle size of the supplementary cementing material plays an important role in its reactivity. The influence of the particle size distribution and fineness on the pozzolanic reactivity of a residual rice husk ash (RHA) was studied and good correlation was observed between fineness and reactivity [14]. Coarse fly ash was ground to various finenesses and effects of grinding on pozzolanic reactivity were investigated. Coarse fly ash showed lower pozzolanic activity than minimum requirement as per standard and ground fly ash below 9 μm had higher pozzolanic activity of more than 100% [15]. Kroehong et al. [16] examined the effect of fineness of palm oil fuel ash on the particle packing and pozzolanic reaction. River sand and palm fuel ash were ground to same fineness and used at different replacement levels of cement in this study to find particle packing as well as reactivity. Pozzolanic activity was increased with fineness of palm fuel ash which was attributed to enhancement in pozzolanic performance. Pan et al. [17] investigated the effect of grinding on pozzolanic activity of sewage sludge ash and observed that pozzolanic activity and compressive strength of concrete significantly improved with increase in fineness.

From the previous research studies, it is clear that processing methods highly influence reactivity of pozzolanic materials. It is imperative to study the effects of different processing methods on the pozzolanic activity of any new supplementary cementitious material. Sugarcane bagasse ash is mainly composed of amorphous silica and can be used as a supplementary cementitious material in concrete [18,19]. Limited studies have been carried out on bagasse ash as supplementary cementitious material. Ganesan et al. [20] investigated the utilization of bagasse ash as pozzolanic material in concrete. In this study raw bagasse ash was directly burnt to 650 °C for one hour and ground to 5.4 μm mean grain size. The performance of bagasse ash as mineral admixture was evaluated in concrete and results suggested that concrete with up to 20% bagasse ash replacement had better performance than control concrete. In a study by Moises et al. [21], raw bagasse samples ground to 5.4 μm mean size were used for performance evaluation in concrete. The effect of burning of sugarcane bagasse ash on pozzolanic activity was studied using Chapelle activity test by Cordeiro et al. [22]; the results of the study showed that the maximum reactivity of bagasse ash was found in the sample that was burnt at around 500 °C. The effect of three different methods of grinding on pozzolanic activity of bagasse ash was investigated in a separate study by Cordeiro et al. [23], in which pozzolanic activity was found to increase with fineness; the study also concluded that grinding to values of D80 (80% passing size) below 60 μm and Blaine fineness above 300 m^2/kg resulted in products that could be classified as pozzolanic material as per ASTM C618-12a [1].

In previous studies, raw bagasse ash was ground to cement fineness and directly used in the concrete for the performance evaluation, without proper characterization as well as adequate understanding of the material. Raw bagasse ash has different particles like coarse fibrous particles, fine fibrous particles and fine burnt particles. It is important to investigate the effect of various processing methods on the pozzolanic performance of bagasse ash including burning, grinding, removal of fibrous particles by sieving and combination of different processing methods to achieve its effective use in concrete. This study investigates the effect of different processing methods on the pozzolanic activity and microstructure of raw bagasse ash, with an objective of suggesting a suitable processing methodology for maximum pozzolanic activity with minimum processing energy inputs.

2. Experimental program

2.1. Sugarcane bagasse ash

Sugarcane bagasse ash was collected from Madras Sugar Limited, Tamil Nadu, India for this study. In sugar industries, bagasse ash is collected by using bag-house filter. Collected bagasse ash is mixed with water and transported to nearest disposal area. Raw bagasse ash collected from such a disposal site was dried at 105–110 °C for 24 h to remove evaporable moisture content, and the dried sample was used for all investigations. Determination of material properties of dried raw bagasse ash was carried out as per standards [24–26]. The determination of standard consistency was performed in accordance with IS 4031-2005 [25] using the mixture of pozzolana and cement in the proportion of 0.2N:0.8, where N is the ratio of specific gravity of pozzolana to specific gravity of cement as specified in IS 1727-1967 [24]. Normal consistency of control cement paste was 31% and for the raw bagasse ash replaced paste was 50%. Generally normal consistency of Indian ordinary Portland cements (conforming to 53 grade as per IS 12269) is 30–32%. The observed value was found to be within the expected range. Presence of coarse fibrous particles in raw bagasse ash increased water requirement for achieving the required consistency. Initial and final setting times were higher than control paste; similar results were also reported in a previous study [20]. Loss on ignition for raw bagasse ash was found to be high (21%). Generally bagasse is burnt around 500–550 °C in the cogeneration boiler to utilize its maximum fuel value. Incomplete burning of plant cellular structured fibers leads to presence of more amount of fibrous particles in the raw bagasse ash. These fibrous unburnt particles are responsible for the higher value of loss on ignition. Soundness test was performed as per IS 1727-2004 [24] and a small expansion, less than permissible limit, was observed in all the specimens. Raw bagasse ash has low specific surface area (145 m^2/kg) as well as low specific gravity (1.91) because of presence of lightweight coarse fibrous carbon particles. Oxide composition of raw bagasse ash was determined by XRF and the results (typical only; not average) are given in Table 1. Raw bagasse ash had more than 70% SiO_2 and 7% CaO.

X-ray diffraction technique (using Cu Kα radiation) was used for mineralogical analysis. Dried bagasse ash sample was ground and sieved through 75 μm sieve. Diffraction pattern of bagasse ash clearly shows the amorphous hump between 20° and 25° 2θ which

Table 1
Physical and chemical characteristics of raw sugarcane bagasse ash.

Physical characteristics		Chemical characteristics	
Characteristics	Raw BA	Oxide	Amount (%)
Specific gravity	1.91	CaO	7.77
Specific surface area (Blaine)	145 m^2/kg	SiO_2	72.95
Moisture content	46%	Al_2O_3	1.68
Loss on ignition	21%	Fe_2O_3	1.89
Normal consistency	50%	MgO	1.98
Initial setting time	195 min	K_2O	9.28
Final setting time	330 min	SO_3	4.45