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Cement Based Matrix Characteristics of Bagasse Ash: A Review

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Abstract: Portland cement which is the main component for making cement based matrix such as mortar, concrete and soil stabilization, its production is energy intensive and contributes to environmental pollution. Also leaving the industrial and agro-waste generated on daily basis to the environment directly elevate the environmental problem. The use of these wastes can reduce the consumption of natural resources and energy sources, as well as lessen the burden of pollutants on environment associated with OPC production. As a result, many researchers have established that the use of Supplementary Cementitious Materials (SCMs) which can not only contribute to economy in construction , but also improve the various properties of concrete-both in its fresh and hardened states. This paper therefore reviewed work carried out by several researchers to explore the potential of Bagasse Ash (BA) as one of SCMs. BA can be used as SCM to achieve durable concrete and also improve the strength of concrete. Physical and chemical properties, pozzolanic activity, strength activity indexand advantages of using BA in concrete are also pointed out. Thus, proper consumption of BA as pozzolanic material in cement based matrix would be a useful step for the production of cost effective and more durable concrete. The study in turn is useful for various resource persons involved in using BA material to develop sustainable construction material.

Keywords: Supplementary Cementitious Materials, Bagasse Ash, Pozzolanic Activity, Concrete.

1.0 Introduction

Concrete is a matrix that constitutes cement, water, coarse and fine aggregate. It has become an indispensable construction material that bypassed the stage of mere four materials mentioned, because the technological trend has evolved various modifications in the conventional materials. The modification entails adding other materials to improve the properties of concrete in terms of mechanical and durability performance. Production of concrete with the incorporation of industrial waste not only provides an effective way to protect our environment, but also leads to better performance of a concrete structure [1]. Engineers and researchers are continuously working for better concrete from strength and durability stand point with the help of innovative Chemical Admixture and Supplementary Cementitious Materials (SCMs)[2]. The principal cementitious material in concrete is Portland cement (PC) and most concrete mixtures contain SCMs that make up a portion of the cementitious component in concrete. SCMs are generally by-products from other processes or natural materials. They may or may not be further processed for use in concrete. Some of these materials are called Pozzolans which by themselves do not have any cementitious properties, but when react with PC form cementitious compound [3].Supplementary cementing materials contribute to the strength gain of concrete by providing additional cementitious compounds; however, the rate of strength gain of concrete containing these materials often differs from the strength gain of concrete that uses Portland cement as the only cementitious material [4].

Industrial wastes, such as blast furnace slag, fly ash and silica fume are being used as supplementary cement replacing materials [5]. Not only industrial by-products but also agro- wastes seemed to be efficient to improve concrete performance as well as its sustainability and among them are rice husk ash, palm oil fuel ash and sugarcane bagasse ash [6]. The use of cement replacement materials in concrete production is an important aspect of concrete technology by which tremendous efforts are being made to address environmental pollution, energy consumption and depletion of natural resources. Cement production consumes high energy and is responsible for 5% of global anthropogenic CO_2 emission (each ton of cement produces about one ton of CO_2) and the use of cement replacement materials improve the properties of concrete [7].

Bagasse is a cellulose fiber remaining after the extraction of the sugar-bearing juice from sugarcane, which is about 40-45% fibrous residue (Fig. 1). Bagasse is one of the biomass sources and valuable by products in sugar milling that often serve as a primary fuel source to supply the energy need to power the plants. Burning bagasse as an energy source yields ash, which is considered as a waste causing disposal problems which is 8-10% by weight [8]. This ash is known as Sugarcane Bagasse Ash (BA) and it has high silica and alumina content [9]. BA is useful as cement replacement material in concrete due to it amorphous silica content ([10] & [11]) and can be used as an excellent pozzolanic addition in blended cement production to attain durable and sustainable concrete instead of being dumped as a waste material [12]. BA is one of the SCM's that has recently been accepted as a pozzolanic material [13] and has other usage apart from its use as cement replacement materials such as, production of activated carbon in groundwater treatment [14], manufacture of tiles in ceramic industry and also as a replacement for sand ([15]&[16]). It is also known as a silica-rich feed for zeolites, pozzolans in cement and concrete, and geopolymers[17]. The research by Kelam and Sandeep [18],indicated that the cost of concrete incorporating BA decreases by 20%-30%.

The nature of ash is altered by controlling parameters such as temperature and rate of heating [16]. Therefore, it pozzolanic activity and performances in cement matrix depends on these parameters. However, the aim of this research is to evaluate the potential improvements and properties of BA by partly substituting cement in concrete.

Figure 1. Sugar Cane Bagasse and Sugar Cane Bagasse Ash [19].

2.0 Calcination of Bagasse for Active BA

Sustainability is an important issue, among all the future development trendsof concrete which is due to its unique advantages and most widely used material in the new century. One way to make concrete sustainable is to utilize industry waste or by-product to replace the raw materials for making concrete, such as cement and aggregates. The industry by-products utilized to replace cement are usually called SCMs[1]. At the same time, the utilization of industrial or agro waste in concrete reduces the environmental impact of Portland cement. Moreover, concrete made with SCMs are proved to be effective to meet most of its requirements in terms of durability and high strength ([20] & [21]). The use of alternative cementing materials prolongs the service life of a concrete structure and saving the resources of raw materials for new buildings through reduction of construction waste due to demolishing of existing buildings and infrastructure. Therefore improving the durability of concrete also contributes directly to its service life and sustainability of natural resources.

The nature of the ash to be used as SCMs need to be classified based on the calcination temperature, heating duration and the rate of heating to avoid poor calcination condition for proper description. Most of the BA obtained from sugar industries are based on uncontrolled temperature and in some cases burnt at temperature range of 1000^oC-1200^oC[22]. Therefore the use of such high temperatures ash worsens the pozzolanic activity of the BA, as crystalline silica called cristobalite is produced and it is less reactive. In their experiments Sharif *et al.*,[22] raw bagasse obtained from a sugar mill can be converted to highly reactive pozzolan by calcining it at 500^oC for one hour duration. Goyal*et al.*,[23], controlled burnt Sugarcane Bagasse at 600^oC for 5 hours in a thermostatically controlled electronic furnace, which produced amorphous bagasse ash with very low carbon contents in it and was reactive as ash-blended mortar specimens with up to 15% substitution of cement gave better strength than control specimens.

N´u˜nez-Jaquez[24], stated that temperature of 650 ^oC is sufficient to obtain BA with amorphous SiO_2 and also has a beneficial effect to protect the steel rebar from corrosion. Usman *et al.*,[9] Reported that Sugarcane bagasse with calcined temperature ranging between 500^oC -700^oC yield reasonable amount silica and alumina that will meet the first evaluation of mineral admixture as per [3] criteria for chemical properties. Ribeiroa and Morelli[25] experiments revealed that BA obtained from calcination temperatures of 500°C, 600°C and 700°C with a heating rate of 10°C/min for 6 hours each presented high pozzolanic activity as determined by the chemical test and according to the XRD results, the BAcalcined at 600°C shows a higher amorphous character, which is illustrated by the greater reactivity of this material. It was further proven that optimal behavior is achieved by the use of SBCA calcined at 600°C in terms of mechanical test.

Tantawy*et al.*,[26], recommended that calcination of BA at 700 ^oC up to 3 hours is the optimum conditions required to produce calcined bagasse ash with high pozzolanic activity to be utilized as a supplementary cementitious material. Therefore, to use BA as a supplementary cementitious material, it must be calcined under controlled conditions to remove unburned carbon, preserve the amorphous silica and improve its pozzolanic properties. As stated by Sultana and Rahman [27], the (X-ray diffraction) XRD results showed that bagasse ash and sugarcane waste ash structure have been changed from amorphous nature (400°C to 800°C) to crystalline materials (1000°C). They further expressed that as temperature increases, the bagasse ash and waste ash colour changes from black to grey and white which indicates that the carbon content present in the samples were reasonably reduced (Fig. 2 and 3). Carbon percentage obtained from elemental analyzer also confirmed minimization of carbon content and loss in ignition also reduced. The same result was also reported by Govindarajan andJayalakshmi [28]when calcined at different temperature (500°C -1000°C). Moreover, BA collected from sugar factor in which the burning temperature is known or unknown can be re-calcined to a stipulated temperature as one of the post treatments that change some of its physical characteristic and chemical composition [29]. Another important point to be cautious of is the temperature at the measuring point are much higher than those reported at the mill boilers [17] therefore accurate temperature monitoring at the combustion seat should be prioritized to ensure a usable final ash product.

Fig. 2UncalcinedBA

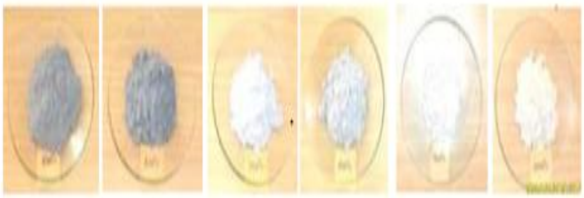

Fig. 3CalcinedBA at different Temperature (500°C -1000°C) [28].

3.0 Pozzolanic Activity of BA

A material is considered pozzolanically active when it contributes to the compressive strength and the activity depends on specific surface area, chemical composition and the active phase content. ASTM C618 [3],prescribes that a Pozzolana should contain SiO_2 + Al_2O_3 +F_2O_3 ≥70wt % based on chemical composition. Suliman and Fudlamola[30], studied the chemical behaviour of BA and indicated that it has more or less the same chemical composition of other artificial pozzolanic material, like fly ash or any other conventional Pozzolana. The Si and Al contents of SCMs combine with the available Ca from the cement gel resulting into Cementitious compound called Calcium Silicate hydrate (CSH) and Calcium Aluminate Hydrate (CAH) [31]. Representation below depicts the simplified reactions of the compound.

$$Ca(OH)_2 \xrightarrow{yields} Ca^{2+} + 2OH^-$$
$$Ca^{2+} + 2OH^- + SiO_2 \xrightarrow{yields} CSH$$
$$Ca^{2+} + 2OH^- + Al_2O_3 \xrightarrow{yields} CSH$$

Many researchers studied the pozzolanic activity of bagasse ash for assessment of it Pozzolanic Performance. Pozzolanic activity of bagasse ash produces more amount of CSH in the bio-cement accelerates and enhances the hydration with strength of the cement matrix system. Hence bagasse ash is a potential replacement material for cement production [32]. The essential of the chemical composition is the amorphous silica that has dual effects either as a filler or Pozzolana. According to Embong*et al.*,[33], soaking Sugar cane bagasse with high concentration of hydrochloric acid is found as essential in order to increase the level of SiO_2 extraction. Because 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.

Effect of grinding also affect the pozzolanic activity of SCMs [34] which increases the fineness of the material as that improve the specific surface area. Habib and Ahmed [35]grounded and sieved BA to a grain size of less than 63μm and it fulfilled the principal requirement of a pozzolanic material due to it high specific surface area, high contents of amorphous silica and calcium oxide. Re-calcination, Sieving and grinding which are post treatment that BA received from sugar mill to improve it pozzolanic potentials. Maldonado-García[29], reported that the SAIs results showed that sieving of the "as received BA" through No. 200 (75μm) mesh is an optimal treatment with minimum energy requirements in comparison to other treatments such as grinding or sieving plus grinding.Aburili[36],used Strength Activity Index (SAI) test to assess the pozzolanic activity of BA which showed that it can be used as SCMs. The research also revealed that the finer the BA the higher it's pozzolanic activity and hence recommended adoption of grain size less than 0.015mm to achieve maximum strength of mortar. Table 1.0 depicts the chemical composition BA by numerous researchers and it can be concluded that BA satisfied pozzolanic requirement with the sum of SiO_2, Al_2O_3 and Fe_2O_3 being greater than 70%.

The quality of pozzolan has often been evaluated according to ASTM C618 [3]. However, recognizing pozzolanic activity using only one method is not suitable, so it is better to combine different methods for evaluation of natural pozzolan [37] such as Frattini test, thermo-gravimetric analysis, Insoluble residue and mineralogical analysis (X-ray diffraction). Therefore, the ASTM requirements can be used as a first step towards recognizing natural pozzolan. Though, there are different standards and guidelines available for evaluation of new alternative SCMs.

There are numerous factors responsible for pozzolanic properties of BA. Crop species and its growing conditions, including regions, combustion temperature and its duration, cooling duration, ash collection methods, and grinding conditions are the controlling parameters responsible for the pozzolanic properties of sugarcane biomass ash [38].

Table. 1.0 Composition of Elemental oxides of Sugarcane Bagasse

Elemental Oxide	**Percentage Composition by weight**							
	[5]	[8]	[15]	[39]	[40]	[41]	[42]	[43]
Calcium Oxide (CaO)	2.15	4.68	11.8	1.50	2.59	4.05	4.52	2.56
Silicon di Oxide (SiO_2)	78.34	77.86	62.43	65.37	87.59	77.25	57.95	87.40
Aluminium Oxide (Al_2O_3)	8.55	2.85	4.28	0.22	0.51	6.37	8.23	3.60
Magnesium Oxide (MgO)	-	3.61	2.51	-	1.65	2.61	4.47	0.69
Phosphorus (P_2O_5)	1.07	0.23		-	1.65	0.59	-	-
Ferric Oxide (Fe_2O_3)	3.61	4.76	6.98	5.98	0.67	4.21	3.96	4.90
Potassium Oxide (K_2O)	3.46	3.19	3.53	-	3.64	2.34	2.41	0.47
Sodium Oxide (Na_2O)	0.12	0.53	-	-	0.17	1.38	-	0.15
Sulfur trioxide (SO_3)	-	-	1.48	-	0.03	0.11	-	0.11
Loss on Ignition (LOI)	0.42	1.86	4.73	21.04	-	1.40	5.0	8.25
$\sum(SiO_2+Al_2O_3+Fe_2O_3)$	90.5	85.47	73.69	71.57	88.77	87.83	70.14	95.9

Bahurudeen*et al.*, [34], proposed a scheme for evaluation of new SCMs which conformed to Indian and International standards. The scheme outlined Material Characterization (Physical, Chemical, Mineralogical and Morphological Characterization), then, Pozzolanic activity evaluation tests (Strength activity index, Electrical conductivity method, Lime reactivity test, Frattini test and lime saturation method) in which more than one method is recommended in this stage, followed by Performance tests (Test of cement paste, Tests on cement mortar and Concrete tests). Agredo*et al.*, [44], conducted various tests on bagasse ash for the mineralogical and morphological characteristics by X-ray diffraction patterns (XRD), Thermo gravimetric analysis and scanning electron microscopy (SEM). They also evaluated the pozzolanic activity of BA using the Frattini test and the strength activity index test (SAI), and concluded that BA can be used as SCMs haven achieved the requirements set by ASTM C618 standard.

4.0 Cement based Matrix Performance Development of BA

Investigating BA performance in concrete has been evaluated by numerous researchers in the field of concrete technology. Performance evaluations in terms of mechanical properties and durability properties have showed excellent results. Bahurudeen*et al.*,[12], reported that Concrete with bagasse ash blended cements showed higher strength compared to control concrete for bagasse ash replacements up to 20% after 28 days of curing. Moreover, resistance against chloride, air, and water permeability was increased to a greater extent for BA blended concrete compared to control and fly ash blended concrete with same level of replacement. Shafiq*et al.*, [41], investigated on compressive strength and microstructure of BA concrete and the result showed that up to 20% level of replacement significantly improved the strength than the reference mix at all ages. The highest compressive strength was obtained at 5% BA replacement level. Likewise, the microstructure of the concrete with BA in terms of interfacial transition zone (ITZ) was enhanced up to 15% level of replacement which strongly confirmed the compressive strength result. Previous result on strength showed that the concretestrength increased as percentage of bagasse ash replacement increased to some level ([5], [39],[44]-[47]) usually not exceeding 10% replacement.

Rao and Prabath[48], conducted an experiment on cement-based composites with bagasse ash, which showed that in the hardened specimens, the specimens with 10% BA demonstrated superior performance in compressive strength, drying shrinkage, water absorption, initial surface absorption, and chloride ion penetration at 56 days. In addition, these specimens showed denser micro structural properties (determined using SEM) than those of OPC. Mechanical strength tests confirmed the actual behavior of BA blended concrete specimen as 10% substitution of OPC with BA gave better strength results in comparison with OPC specimen [49].

Dhengare*et al.*, [40], investigated on BA as SCM in two different grades of concrete (M25 and M35) with the ash passing through No. 600 Sieve. The result showed that BA gives higher strength than control concrete. In the case of compressive strength up 20% replacement yielded better result for M25 and 10% for M35 after 28 days curing. While for Flexural strength was about 15% for both grades. The maximum split tensile strength was obtained at 10% BA replacement in M25 and in case of M35 was 10 % BA replacement for 28 days curing.

It was found by Geerthana*et al.*, [50], that the cement could be advantageously replaced with BA up to maximum limit of 20% can significantly give higher compressive strength and split tensile strength compare to that of the concrete without BA.

Srinivasan and Sathiya[5], reported that Modulus of Elasticity and density of concrete decreases with increase in BA. The result further showed that BA increases workability of fresh concrete; therefore use of superplasticizer is not substantial. So using BA would be useful in the case of high performance concrete where, the water-cement ratio is usually low, with small amount of superplasticizer.

Rukzon and Chindaprasit[51], determined the compressive strength, the porosity, the coefficient of water absorption, the rapid chloride penetration and the chloride diffusion of high strength concrete containing BA. The test results indicate that the incorporation of BA up to 30% replacement level increases the resistance to chloride penetration. Besides, the use of 10% of BA produced concretes with good strength and low porosity. Reasonably, the substitution of 30% BA is acceptable for producing high-strength concrete. Although in a more recent study by Mohamed *et al.*,[52] their result revealed that addition of bagasse ash to cement up to 15% has improved the compressive strength of mortar. While the addition of 20% bagasse ash to cement results in decreasing the soundness of the cement and improving its fineness.

In addition to strength advantage of BA, its effect on durability has also been studied. Baharududeen and Santhanam[13], currentlyinvestigated on the durability performance of BA-based Cement concrete by five different methods (Rapid chloride penetration test, Chloride conductivity test, Water Sorptivity test and Torrent air permeability test) and significantly enhance its durability performance. Amin [43], usedBA in Concrete and investigated its impact on the Strength and Chloride Resistivity. The results indicated that it is an effective mineral admixture and pozzolan with the optimal replacement ratio of 20% cement, which reduced the chloride diffusion by more than 50% without any adverse effects on other properties of the hardened concrete. This is incompliance with the findings ofN´u˜nez-Jaquez[24] that the use of sugar cane bagasse ash as a partial replacement of cement has a beneficial effect to protect the steel rebar from corrosion because it reduced the pore size in the cement paste, which minimized the ingress of aggressive ions into concrete. Concrete containing BA had a lower corrosion rate when compared to concrete without the addition of BA.

Habbed and Ambi[53], studied the effect of BA on ternary blended concrete containing Ground Granulated Blast Furnace Slag (GGBS) at 30 % fixed replacement level, while the BA was varied from 0%-30% and for comparison purpose normal concrete with 100% OPC was also tested as control. After studying the strength and durability properties, it was found that the ternary blended concrete with 10% BA and 30% GGBS showed greater improvement in the properties than all other mixes.

The pozzolanic activity of BA is not only effective in enhancing the concrete strength, but also in improving the permeability characteristics of it [18]. Xu *et al.*,[54], have conclusively reported that BA when successfully used improve the short-term mechanical properties and long-term durability of mortar, concrete, and other construction materials.

Aher*et al.*,[55], investigated the fresh performance of concrete with BA using slump cone test, Compaction factor test and Flow table test and observed that for all grade of concrete increase in BA decreases the value of workability.

BA has also been explore in other cement based matrix aspect of soil stabilization. Batari*et al.*,[56], recommended the use of 5% BA and 8% cement as the optimum blend for the stabilization of black cotton soil to be used as sub-base in flexible pavement construction in accordance with the requirement of the Nigerian Federal Ministry of Works.

5.0 Conclusion

This review paper aimed at improving our knowledge on the application of BA and also demonstrating its capacity to reach all technical requirements. It is obvious from the above reviewed literature that BA has amorphous silica when calcined at temperature range between 600°C to 800°C at 10°C/min for 5- 6 hours. Higher amount of fine amorphous silica (SiO_2) in a pozzolan will normally increase its pozzolanic reactivity. In addition to calcination for effective evaluation of BA, ASTM C618 should serve as a first step followed by other methods such as Electrical conductivity, lime reactivity, Frattini test and lime saturation. XRD and insoluble residue also assist for the mineralogical assessment. Thus, BA With high amount of silica, alumina and calcium oxide as the main constituents, should be used in cement and concrete due to its high pozzolanic reactivity. In terms of performance evaluation BA has numerous advantages such as development of high early strength, reduction in water permeability, and appreciable resistance to chloride permeation and diffusion. It was also seen that up to 20% partial replacement of BA can save cost of cement with better strength than control concrete. Also, the utilization of BA could solve the problem of its disposal, therefore keeping our environment free from pollution and land filling issues. Finally it usage would provide concrete products with high technical performance.

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