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Pozzolanic Activity of Sugarcane Bagasse Ash Concrete

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Abstract: **Bagasse is a cellulose fiber remaining after the extraction of the sugar-bearing juice from sugarcane. It is a valuable byproduct in sugar milling and is often used as a primary fuel source due to its high calorific value required to supply most energy requirement for most sugar factory operations. The burning of baggase leaves solid black particles known as sugar cane baggase ash (SCBA). Utilization of this waste material as partial replacement of cement in concrete provides a satisfactory solution to some of the economical, environmental and concerns associated with waste management. SCBA is normally disposed as landfills, exposure to these dusts causes chronic lung condition and its application on agricultural lands results to heavy metals concentrations in soils. It has been reported by several researchers that SCBA has intrinsic characteristic such as high content of silica in the form of quartz. This research mainly focused on SCBA disposed as solid wastes from Nzoia Sugar Company, Bungoma County in western Kenya. The research design adopted was Experimental. Granulometric indices of SCBA were determined through sieving the samples and weight retained. Strength Activity Index test, was used to assess the Pozzolanic activity of SCBA. Results showed that SCBA exhibits high Pozzolanic activity, hence can be used as a substitute cementitious material.**

Keywords: **Sugar Cane Baggase Ash, Strength Activity Index, Silica, Nzoia Sugar Company, Pozzolanic Activity.**

1. INTRODUCTION

Concrete is one of the most commonly used construction material in the world. It's basically composed of three components: cement, water and aggregates. [1] Established that, combination of a number of ingredients such as Sugar cane baggase ash (SCBA) can generally be used in concrete production. Sugarcane is one of the major crops grown in over 110 countries and its total production is over 1500 million tons, this is according to [2]. Baggase is a cellulose fiber remaining after the extraction of the sugar-bearing juice from sugarcane. The burning of baggase leaves solid black particles known as SCBA which are normally disposed as landfills, spread over farms or dumped in ash ponds. [3] Observed that these landfills are a nuisance to communities surrounding industrial areas and are a frequent cause for resistance to industrial expansion and rehabilitation of sugarcane farmlands. The objective of this research was to determine the Pozzolanic activity of SCBA, specifically from Nzoia Sugar Company (NSC), which is dumped as landfill. NSC, one of the eight sugar factories in Kenya is located in Bungoma County of Western Province with a nucleus and out-growers size of 3,400 and 27,000 Hectares respectively. It produces at-least 5,600 Tons of SCBA per month. The pozzolanic activity of the SCBA was determined based on compressive strength according to the procedures outlined in [4] and specified by [5]./ In this test, the 7 days and 28 days compressive strength of cement - SCBA mixture was compared to that without SCBA. Samples were prepared for each grain size of SCBA. The mixture (SCBA + cement) should provide at-least 75% of the strength of the control (cement only) at 7 day and 28 day. The water requirement and compressive strength for the strength activity indices were determined according to the procedure given in [6]

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2. MATERIALS

SCBA samples were purposely selected from three dumping sites. Different grain sizes were sort to produce various SCBA samples. SCBA consist of particles with various shapes and sizes. The boiler furnace temperature was around 450°C. According to [7], burning baggase between 400ºC and 600ºC produces an increase in the Pozzolanic Activity Index due to loss of carbon during the calcination process. Cement used in this study was type 1 OPC, purposely procured locally. This cement binder complied with requirement of [8]. Sand, free from debris was purposefully purchased locally. The sand particles were packed to give minimum void ratio and high voids content leading to requirement of more mixing water. The sand had a minimum size of 150micron to maximum particle size of 4.75 mm and was used as fine aggregate according to [9]. The water used was in accordance within the [10] recommendations. In this study, casting and curing of specimens were done using potable water free from deleterious materials. Water plays an important role in concrete production. It starts the reaction between the cement and aggregates and helps in hydration of the concrete mix. The apparatus used to determine the grain size distribution of all the aggregates were; Balance, a set of sieves and an oven. The sieve sizes used were 75µm, 150µm. 300µm, 600µm, 1mm. 2mm, 3mm, 6mm, 7mm, 8mm, 9mm, 10mm, 14mm and 20mm. For determination of hydrometer analysis of sand, the material and apparatus used were: dispersing agent (sodium hexametaphosphate (40 g/L)) solution and a hydrometer.

The particle size distributions of SCBA, OPC and ballast were determined using the [11] specifications. This method of test covers the requirements in addition to or superseding the requirements of ASTM for the determination of the particle size distribution of fine and coarse aggregates. A weighed sample of dry aggregate was separated through a series of sieves of progressively smaller openings for determination of particle size distribution. This test method was used to separate particles into size ranges and to determine quantitatively the mass of particles in each range. These data were combined to determine the particle-size distribution (gradation). This test method used a square opening sieve criterion in determining the gradation of SCBA and OPC for sieve 5mm, 2mm, 1mm, 0.6mm, 0.3mm, 0.150mm, and 0.075mm. Sample processing adopted air drying method to obtain the various specimens.

This test method was also used to separate particles into size ranges and determine quantitatively the mass of particles in each range. As the particle size distributions are continuous, a total of 7 indices; D_2, D1, $D_{0.6}$, $D_{0.3}$, $D_{0.15}$, $D_{0..075}$, and $D_{<0.075}$ were used to characterize the granulometric sizes of the SCBA samples and are the corresponding values representing samples retained on sieve size 2mm, 1mm, 0.6mm, 0.3mm, 0.15mm, 0.075mm and passing sieve 0.075mm respectively. The portion for sieve analysis was obtained from the sample by the use of a sample splitter. Fine (SCBA) and course (ballast) aggregate were thoroughly mixed and in a dry condition prior to splitting. The selection of a portion for test of an exact predetermined weight was not be attempted. However, the weight of the sample portion before sieving was also determined and recorded. All aggregates were sieved for 10 minutes. The weight of each sieve as well as the bottom pan to be used in the analysis was noted. In addition, the weight of the bottom pan with its retained fine aggregate was recorded. The portion of the SCBA sample for sieve analysis was weighed, after drying, approximately 500 grams was weighed to the nearest 0.1 gram. The portion of ballast for test was weighed to the nearest 10 grams on the larger balance except for sieve size less than 4mm which was weighed to 1 gram on the smaller balance

According to AASHTO classification, the notation D_{xx} refers to the size D**,** in mm, for which xx percent of the sample by weight passes a sieve mesh with an opening equal to D. The D_{10} size, sometimes called the effective grain size, is the grain diameter for which 10% of the sample (by weight) is finer. The D_{50} size, called the median grain size, is the grain diameter for which half the sample (by weight) is smaller and half is larger. Two parameters are used to describe the general shape of the grain-size distribution curve. Gradation of a soil was determined by calculating the coefficient of uniformity, C_u, and the coefficient of curvature, C_c, of the soil and comparing the calculated values with published gradation limits as stipulated by Unified Soil Classification System (USCS).

[12] Showed that grain size distribution curves can be classified and identified as either log-normal distribution, Talbot distribution or bimodal distribution. They further stated that the grain distribution of aggregates can be classified and identified visually based on the shape of size distribution and size distribution

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3. METHODS

A sample of fine sand to be used in all the tests was taken from the bottom pan of the sieve set, placed it into a beaker, and 125mL of the dispersing agent (sodium hexametaphosphate (40 g/L)) solution added. The mixture was stirred until the SCBA sample was thoroughly wet and allowed to soak for at least ten minutes. While the SCBA sample was soaking, 125mL of dispersing agent was added into the control cylinder and then filled with distilled water to the mark. The reading at the top of the meniscus formed by the hydrometer stem and the control solution were taken. A reading less than zero was recorded as a negative (-) correction and a reading between zero and sixty were recorded as a positive (+) correction. This reading is called the zero correction. The meniscus correction is the difference between the top of the meniscus and the level of the solution in the control jar (Usually about +1). The control cylinder was shaken in such a way that the contents were mixed thoroughly. Silt content was then determined.

Strength Activity Index (SAI) test, was used to assess the Pozzolanic activity of SCBA. The 7 and 28 days compressive strengths of test mortar was prepared with a 20 % SCBA substitution for cement on a mass basis, these were compared to those of a control mortar. The control mortar was prepared with a water-to-cement ratio by mass (*w/c*) of 0.484, while the water content of the test mixture was adjusted so that there was an equivalent flow to that measured for the control. The SAI of the SCBA samples was determined based on the compressive strength set by the ASTM specifications. The OPC in the mortar was partially replaced by 20% SCBA and tested. The process used to replace the Portland cements was based on BS 3892 (1997). The cast iron mould had dimensions 150mm x 150mm with each mortar (1:3 mix) per mould weighing 7Kg. There were 7 specimen specifications prepared; control (cement: sand @ 1:3) and the remaining 6 specimen had SCBA (as shown in Table 1.0) contents with mortar mix cement: SCBA: sand 0.2: 0.8: 3. 3 samples of each specimen were prepared, to cater for 7 and 28days curing period, hence a total of 42 samples.

The Control mortar was prepared by mixing 10.5Kg of OPC and 31.5Kg of Sand and 5.4Kg of water. The test mortar mixture was prepared by mixing 8.4Kg of OPC, 2.1Kg of SCBA and 31.5Kg of sand. The water to binder ratio was altered so that the mixture had the same flow properties as the control mortar (±5 mm). The mortar pastes were mixed for 30 seconds and cast into the moulds with the aid of a vibrating table.

Table 1. Test mixtures used in the Strength Activity Tests for different SCBA grain sizes

Mortar Samples	Particle size (mm)	0PC (Kg)	Sand (Kg)	SCBA (Kg)	Water (Kg)
SAI/Control	No. SCBA	10.5	31.5	0	5.4
D_2	> 2	8.4	31.5	2.1	5.4
D_1	2 - 1	8.4	31.5	2.1	5.4
$D_{0.6}$	1 - 0.6	8.4	31.5	2.1	5.7
$D_{0.3}$	0.6 - 0.3	8.4	31.5	2.1	5.8
$D_{0.15}$	0.3 - 0.15	8.4	31.5	2.1	5.8
$D_{0..075}$	0.15 - 0.075	8.4	31.5	2.1	5.8
D_0	< 0.075	8.4	31.5	2.1	6

A total of 48, 150mm cubes were cast; three for each of the above specimens and tested for 7 and 28 days. After molding, the specimens and moulds were placed in the moist room and maintained 23 ± 2ºC for 24 hours. Then the cube samples were removed from the moist room, and de-moulded from their respective moulds. The cubes were then placed and stored in saturated limewater for 1 day. All blocks were de-moulded after 24 hours and placed in a water bath at 23 °C for 6 or 27 days. They were then removed from the bath, surface dried and the compressive strength was tested at 7 and 28 days. The cubes were tested using a universal compression machine (Model: Budensbery - 2000kN) test system with a 2000 KN capacity loading frame. The compressive strength was measured using a constant loading rate of 18 MPa/min.

The average compressive strength was determined from three mortar samples for each specimen at the ages of 7 and 28 days. The results of the total strengths are the averages of the three tests for each sample are presented as percentage strength relative to the control mortar. Therefore, the results are presented as in equation 1.0

SAI = A/B x 100……………………………………………………………………………...1.0

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Where:

A = Unconfined compressive strength of the test SCBA specimen (Nmm^{-2})

B = Unconfined compressive strength of the control mortar (Nmm^{-2}).

According to [13] SAI results greater than 0.80 after 28 days indicate positive Pozzolanic activity of Pozzolan for a cement replacement of 20%. [5] Requires a SAI greater than 0.75 after 7 and 28 days for natural Pozzolan at a cement replacement of 20%.

4. RESULTS AND DISCUSSIONS

Grain Size Distribution of OPC:

A distribution of particle sizes or particle size distribution (PSD) is a fundamental characteristic of cement powder. Since there are no standard procedures that adequately cover the broad particle size range associated with Portland cement powder, [16] performed laser diffraction techniques to determine PSD and results stipulated as shown in figure 1 and figure 2

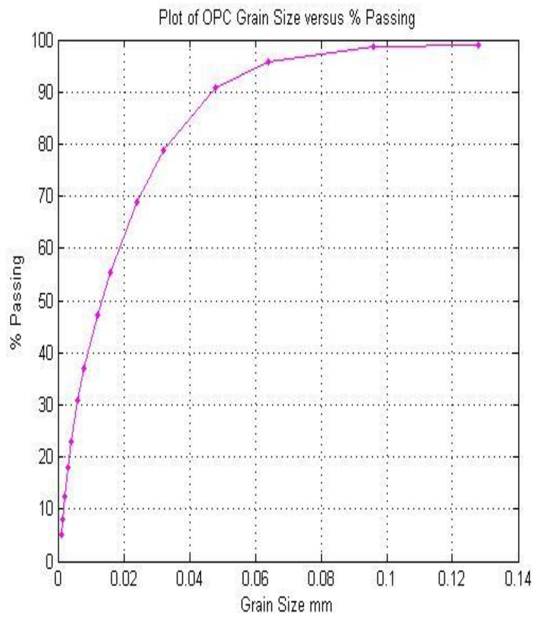

Figure 1 Grain size distribution of OPC.

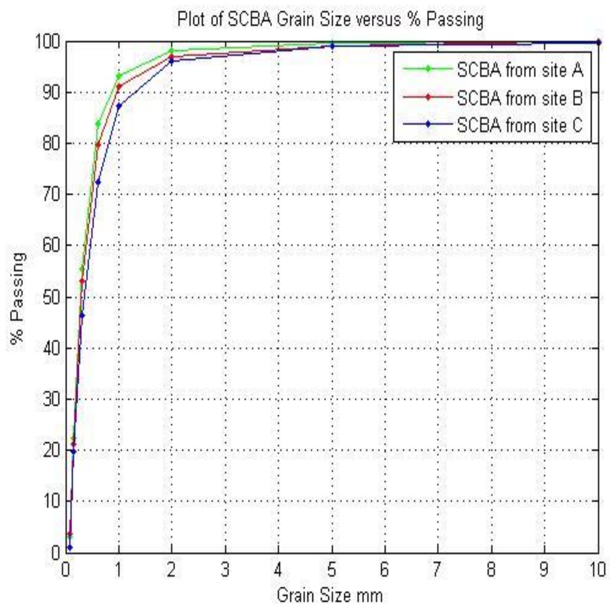

Figure 2 PSD of SCBA from the different sites

Grain Size Distribution SCBA:

Below are PSD curves for different SCBA samples from the 3 dumping sites

The grain size distribution and the density curve of both OPC and SCBA exhibit a trend where the density distribution has a single peak, hence can be classified as log-normal distribution. Based on ASHTOO Classification standards, the *coefficient of uniformity*, C_u is a crude shape parameter and is calculated using the following equation

$C_u = D_{60} / D_{10}$……………………………………………………………………………………2.0

The *coefficient of curvature*, C_c is a shape parameter and is calculated using the following equation:

$C_c = (D_{30})^2 / D_{10} \times D_{60}$…………………………………………………………………………..3.0

SCBA can categorized as semi – fine to fine aggregate (< 5mm), hence according to USCS, the following criteria must be met:

$C_u \geq 6$ & $1 < C_c < 3$………………………………………………………………………..4.0

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If both of these criteria are not met, the grains would be classified as poorly graded or SP. If both of these criteria are met, they would be classified as well graded or SW. Table 2 shows classification of OPC and all the SCBA samples including the effective size of particle size distribution (PSD) at 10% (D_{10}), 30% (D_{30}) and 60% (D_{60}) percentage passing.

Table: 2. Classification of Samples

Sample	D_{10} (mm)	D_{30} (mm)	D_{50} (mm)	D_{60} (mm)	C_u	C_c	Classification
OPC	0.002	0.007	0.014	0.02	10	1.225	SW
A	0.1	0.25	0.25	0.4	0.4	1.56	SP
B	0.1	0.25	0.45	0.6	6	1.04	SW
C	0.1	0.2	0.3	0.5	5	1.8	SP
D	0.1	0.2	0.45	0.6	6	1.04	SW

Strength Activity Index Test Results:

Below is a Table showing SAI results for different SCBA grain sizes at 7 and 28 days curing periods. M1, M2 and M3 denotes the 3 moulds per each specimen and M the average compressive strength. C was the control mix.

Table: 3. Strength Activity Index Test results of SCBA of different Grain Sizes

	7 days					28 days				
	f_{cu} (N/mm^2)				SAI (%)	f_{cu} (N/mm^2)				SAI (%)
	M1	M2	M3	M	SAI	M1	M2	M3	M	
C	8.8	9.4	9.1	9.1	100	10.1	10.2	10.1	10.1	100
D_2	5.0	5.0	5.1	5.0	56	4.9	4.8	5.0	4,9	48
D_1	5.2	5.0	5.1	5.1	56	5.7	5.6	5.7	5.7	56
$D_{0.6}$	5.2	5.3	5.3	5.3	58	6.5	6.6	6,8	6.6	65
$D_{0.3}$	7.2	6.7	6.2	6.7	74	7.0	7.1	7.1	7.1	70
$D_{0.15}$	7.3	7.4	7.5	7.4	81	8.0	8.0	7.9	8.0	79
$D_{0..075}$	8.1	8.1	8.2	8.1	89	8.7	8.6	8.8	8.7	86
$D_{<0.075}$	8.8	8.6	8.7	8.7	96	8.9	9.1	8.7	8.9	88

The above tabulated results were used to develop bar chart presentations of different SCBA grain sizes as shown in figure 3 and figure 4 for SAI test results for mortar samples at 7 and 28 days curing periods, through Matlab R2013a program application and analysis.

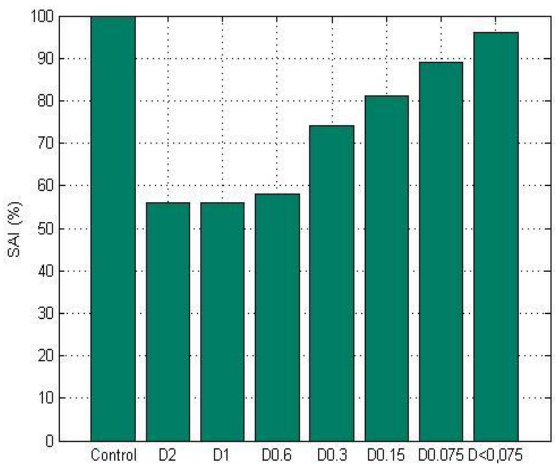

Figure: 3. Results of SAI test after 7 days.

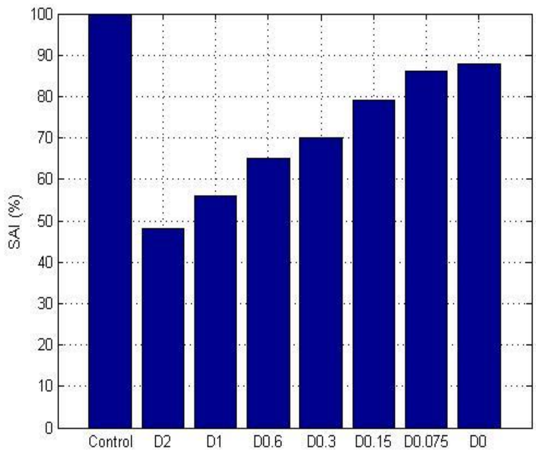

Figure: 4. Results of SAI test after 28 days

From above figures (3 and 4), the SAI's of blended mortar increases with decrease in grain size of SCBA. SAI above 75% had SCBA grain sizes retained on sieve sizes 0.15mm. 0.075mm and passing 0.075mm for both seven (7) days and eight (8) curing period. As shown in Figures 3.0 and 4.0, at both curing times of 7 and 28 days, blended mortars with finer SCBA will yield the SAIs well beyond 75%, which is the minimum requirement to classify a material as a Class N pozzolan according to ASTM this in spite of its meager amorphous SO_2 according to [14]. At both curing times, higher SAIs is observed for the fine SCBAs, in agreements with similar trends in similar tests conducted by [15],[16] . However filler effect which is to more extent is related to fine size of aggregate in mortar can be said to be a major contributor of higher SAIs, hence a factor considered when designing grain size of OPC. [16] showed that burning baggase between 400ºC and 600ºC produces an increase in the Pozzolanic activity index with increasing firing temperatures due to the loss of carbon The furnace temperature for NSC boilers were around 450°C, however these authors suggest that the optimal temperature for the production of Pozzolanic SCBA is 600ºC because at this temperature it is possible to generate predominantly amorphous silica with a SAI of 77%.

5. CONCLUSIONS AND RECOMMENDATIONS

SCBA exhibits high Pozzolanic activity, hence can be used as a substitute cementitious material (SCM). The finer the SCBA the higher its Pozzolanic activity, hence it is recommended adopt grain size < 0.015mm to achieve maximum strength in mortars. It is further recommended to study contributory factor of filler effect of SCBA in Pozzolanic activity enhancement in mortars. The results should help promote the use of industrial SCBAs as an SCM, provided finer particles will be applied thereby enhancing both the filler and the Pozzolanic effects.

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