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Characterization of Compressive Strength of Concrete Blended with Sugarcane Bagasse Ash

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Abstract: **A number of researchers today are focusing on ways of utilizing either industrial or agricultural waste as a source of raw materials for production of construction products. Presence of silica in Sugar Cane Bagasse Ash (SCBA) contribute to improved Pozzolanic activity, but the silicate content may vary from ash to ash depending on the burning conditions of bagasse and the properties of soil on which the sugarcane is grown. The main objective of this research was to characterize the compressive strengths of concrete by varying the SCBA and (Ordinary Portland Cement) OPC contents. The SCBA used for this research was sampled from Nzoia Sugar Company (NSC), one of the key players in Kenya's Sugar Industry. The two variables; cement and SCBA content were applied to establish the concrete's workability and compression strength at different curing periods (7, 14 and 28 days). Non-probability technique of sampling, specifically purposive sampling was applied in selecting the units that was included in all the samples. The research concluded that SCBA grain size of < 0.075mm and optimum SCBA content of 10% would provide the highest workability and compressive strength in SCBA blended concrete.**

Keywords: **Sugar Cane Bagasse Ash, Silica, Workability, Compressive Strength.**

1. INTRODUCTION

A number of researchers today are focusing on ways of utilizing either industrial or agricultural waste, as a source of raw materials for construction products. According to Srinivasan R and Sathiya K. (2010), waste, utilization would not only be economical, but may also result in foreign exchange earnings and environmental pollution control. Since the early 1980's, Marcos O, Ilda F, Conrado S and, Jairo A. (2009) stated that there has been an enormous demand for a mineral admixture and in future this demand is expected to increase even more. Due to this, requirements for more economical and environmental-friendly cementing materials have led interest for partial cement replacement materials.

Bagasse is a cellulose fiber remaining after the extraction of the sugar-bearing juice from sugarcane. It is a valuable byproduct in sugar milling that is often used as a primary fuel source due to its high calorific value required to supply energy which ensure Factory's operations. The burning of bagasse leaves solid black particles known as sugar cane bagasse ash (SCBA). Cordeiro C., Toledo F and Fairbairn R, (2010), concluded that SCBA can be an important raw material for the pozzolan production, mainly in tropical countries and also established that the pozzolanic activity of the bagasse can be attributed to the presence of amorphous silica (SiO_2). Abdolkarim A and Amin Z, (2013).,Showed that the use of SCBA in concrete as 10% cement replacement causes slump increase and compressive strength and delayed in initial and final setting time.

SCBA is normally disposed as landfills, spread over farms or dumped in ash ponds. Nzoia Sugar Company (NSC) monthly sugarcane processed is between 70 – 80,000 Tons, meaning SCBA produced by this company is at-least 5,600 Tons per month. In his study, [5] stated that exposure to these dusts causes chronic lung condition known as pulmonary fibrosis, more specifically referred to as bagassosis. Further, loading of ash to soils enhances its salt content resulting to salinity problems which may not only retard plant establishment and growth but also affect the soil and groundwater quality.

The main objective of this research was to characterize the compressive strengths of blended concrete by varying the SCBA and OPC contents. [6] And several other researchers showed that SCBA composition consisted of high proportions of silica (SiO_2), a major component of cement. Moreover, the poverty levels in Nzoia sugar belt are low and this is due to high dependence on sugarcane farming as shown by [7]. Commercialized production of precast SCBA blended concrete components may be a noble venture and improve economic wellbeing of surrounding inhabitants.

Materials:

The SCBA used for this research was fetched from NSC, one of the key players in Kenya's Sugar Industry. It is located in Bungoma County, Bungoma South District, 5Km from Bukembe, off the Webuye-Bungoma highway. Engineering properties of concrete were investigated from Public Works Lab in Kakamega. This Institution was purposefully selected. SCBA samples were sampled from three sites purposely selected. The furnace temperature was around 450°C. Cement used in this study was type 1 OPC, and procured locally. This binder complied with requirement of [8]. Ballast was also purposefully purchased locally. This coarse aggregate passing through 20 mm sieve and retained on 12.5 mm sieve as recommended in [9] was used for all the specimens. The water used was of drinking quality in accordance with the recommendations stipulated in [10]. The apparatus used in the flakiness index test were; A gauge (of any suitable form) of metal 1,6 mm thick and having one slot for each size of fraction to be tested (the slots were rectangular in shape); A balance to weigh up to 4 kg, accurate to 1gram and a Riffle box). The apparatus used in determination of the Particle size distribution (PSD) test were; the Balance, A set of sieves and an Oven. The test for compressive strength of SCBA concrete applied moulds, tapping rod, a vibrator, a mallet and various measuring devices.

2. METHODS

The methods corresponded to compressive strengths characterization of SCBA concrete. It was significant initially to carry out the flakiness index and grain size distribution on aggregates.

Flakiness Index Test:

Testing for Flakiness Index (FI) of any course aggregate samples is key to check for concrete durability. It was hence key to determine the FI of the ballast sample to be used to mould the SCBA concrete in this study. The FI of ballast sample was found by separating the flaky particles and expressing their mass as a percentage of the mass of the sample tested. The test was not applicable to material passing a 6.30 mm sieve or retained on a 63.0 mm sieve. This test method was used to determine the percentage of particles in ballast that have a thickness (smallest dimension) of less than one-half of the nominal size. The FI of the ballast sample was determined by gauging screened-out fractions with the appropriate slot(s). Individual size fractions were separated and each particle that passes through the appropriate slot is considered a flaky particle. This test was as per standards conformed in [11].

Grain Size Distribution:

The particle size distributions (PSD) of SCBA, sand and ballast were determined using [12] specifications. Sieving of samples of these SCBA were done and weight retained on each sieve was taken and expressed as percentages of the total sample weight, from which the granulometric indices was determined. A weighed sample of dry aggregate (sand and ballast) was separated through a series of sieves of progressively smaller openings for determination of particle size distribution (gradation). This test method used square opening sieve criterion in determining the gradation of SCBA 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. As the PSD is continuous, a total of 7 indices; D_2, D1, $D_{0.6}$, $D_{0.3}$, $D_{0.15}$, $D_{0..075}$, and D_0 were used to characterize the granulometric sizes of the SCBA samples. D_{2} was the material particle size retained at sieve size 2mm whereas, D_1, $D_{0.6}$, $D_{0.3}$, $D_{0.15}$, $D_{0..075}$, and D_0 were the corresponding values representing SCBA samples retained on sieve size 1mm, 0.6mm, 0.3mm, 0.15mm, 0.075mm and < 0.075mm respectively.

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The process for grading the aggregates was in accordance with the Unified Soil Classification System (USCS) which was determined by reading the grain size distribution curve produced from the results of laboratory tests. Gradation was determined by calculating D_{10} size, sometimes called the effective grain size, D_{50} size, called the median grain size, the coefficient of uniformity, C_u, and the coefficient of curvature, C_c, of the aggregate and comparing the calculated values with gradation limits as stipulated by USCS.

Characterization of Compressive Strengths of SCBA Concrete:

Compressive strengths characterization of SCBA concrete both fresh and old (or one undergoing the curing process) was determined by conducting Slump and Compressive Strength tests respectively. The cast iron mould had dimensions 150mm x 150mm with each concrete (1:2:4 mix or class 20) per mould weighing 7Kg. There were 7 specimen specifications prepared, one of the mixes was made of 100% cement (no SCBA content), denoted by C and called the control mix. The remaining 6 mixes were prepared by adding SCBA content as partial replacement to cement i.e., 5, 10, 15, 20, 25 and 30%, respectively. (See Table 1.0). The water cement ratio of 0.45 for the control mix was maintained for all the specimen. 3 samples of each of the 7 specimen for SCBA grain sizes retained in sieve size 2mm, 1mm, 0.6mm, 0.3mm, 0.15mm, 0.075mm and passing through 0.075mm were prepared, to cater for 7, 14 and 28days curing period, hence a total of 147 samples were prepared. All concrete ingredients were mixed according to the procedure given in [12].

3. SLUMP TEST

This method of test covered the procedure for determining the slump of freshly mixed concrete and reflects testing procedures found in [13]. A sample of freshly mixed concrete was placed and compacted by rodding in a mold shaped as the frustum of a cone. The mold was raised and the concrete allowed to subside. The distance between the original and displaced position of the center of the top surface of the concrete was measured and reported as the slump of the concrete.

Table: 1. Concrete mix proportions

Mix description	OPC (Kg)	SCBA (Kg)	Sand (Kg)	Quarry Dust (Kg)	Water (Kg)
Control	1.0	0	3.0	4.0	2.2
5% SCBA	0.95	0.05	3.0	4.0	2.2
10% SCBA	0.9	0.1	3.0	4.0	2.2
15% SCBA	0.85	0.15	3.0	4.0	2.2
20% SCBA	0.8	0.2	3.0	4.0	2.2
25% SCBA	0.75.	0.25	3.0	4.0	2.2
30% SCBA	0.7	0.3	3.0	4.0	2.2

Batching was by weight and a water/cement ratio of 0.55 was used for all mixes. Mixing was done manually on a smooth concrete pavement. The SCBA was first thoroughly blended with OPC at the required proportion and the homogenous blend was then mixed with ballast at the required proportions. Water was then added gradually and the entire concrete heap was mixed thoroughly to ensure homogeneity.

Compressive Strength Test:

The compressive strength was determined using 150 mm cubes at the age of 7, 14, and 28days, respectively as curing periods. During compression test, the load on the cube was applied at a constant rate of 3.0 KN/s according to [14]. Three (3) concrete cubes for each percentage replacement of OPC with SCDA and the 7 different grain sizes including the control were tested for saturated surface dry bulk density and crushed to obtain their compressive strengths at 7, 14 and 28 days of curing. The constituent materials of concrete remained uniformly distributed within the concrete mass during the various stages of handling and full compaction was achieved, and making sure that the characteristics of concrete which affect full compaction like consistency, mobility and compatibility were in conformity with relevant codes of practice.

Immediately after molding and finishing, the specimens were stored for a period up to 48 h in a temperature range from 60 and 80°F [16 and 27°C] and in an environment preventing moisture loss from the specimens. Upon completion of

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initial curing and within 30 min after removing the molds, cure specimens with free water maintained on their surfaces at all times at a temperature of 23 ± 3°C using water storage tanks.

4. RESULTS AND DISCUSSIONS

Flakiness Index of Ballast:

Aggregate is termed as flaky when its least dimension (i.e. thickness) is reasonably small compared to its other two dimensions (width or length). The flakiness index (FI) is the % by weight of those particle present in an aggregate sample whose greatest dimension (length) is greater than 9/5th of their mean dimension. The presence of these particles in concrete should not be more than 15% to obtain durable concrete, according to [15]**.** Table 2.0 gives the results of the tested ballast sample. The ballast sample used size range was maximum of ½ " hence then need to adopt sieve size range of 6 – 14mm for the ballast FI determination. .

Table: 2. FI results of Ballast sample

Sieve Size (mm)	Mass Retained (g)	Total Mass (g)	Mass Passing (g)
14	618.5	326	46
10	189.2	295	35
6	131.9	231	26
Total		**852**	**104**

Flakiness Index =

$$\frac{\text{(Total mass of Aggregate pass slots)}}{\text{(Mass of test sample)}} \times 100$$

From the results above

FI = 104/852

= 12.2%

Grain Size Distribution of Ballast:

From Table 3.0 below, the particle size range of ballast was from 2mm to 20mm. The total sample weight was 1590g.

Table: 3. Grain Size Distribution of Ballast sample

Grain Size (mm)	Weight Retained (g)	% age Retained (%)	Cumulative % age Retained (%)	% age Passing (%)
20	-	0	0	100
14	618.5	38.9	38.9	61.1
10	189.2	11.9	50.8	49.2
9	159	10	60.8	39.2
8	144.7	9.1	69.9	30.1
7	151	9.5	79.4	20.6
6	131.9	8.3	87.7	12.3
5	33.3	2.1	89.8	10.2
3	11.3	0.7	90.5	9.5
2	4.7	0.3	90.8	9.2
Pan	45	2.8	93.6	-

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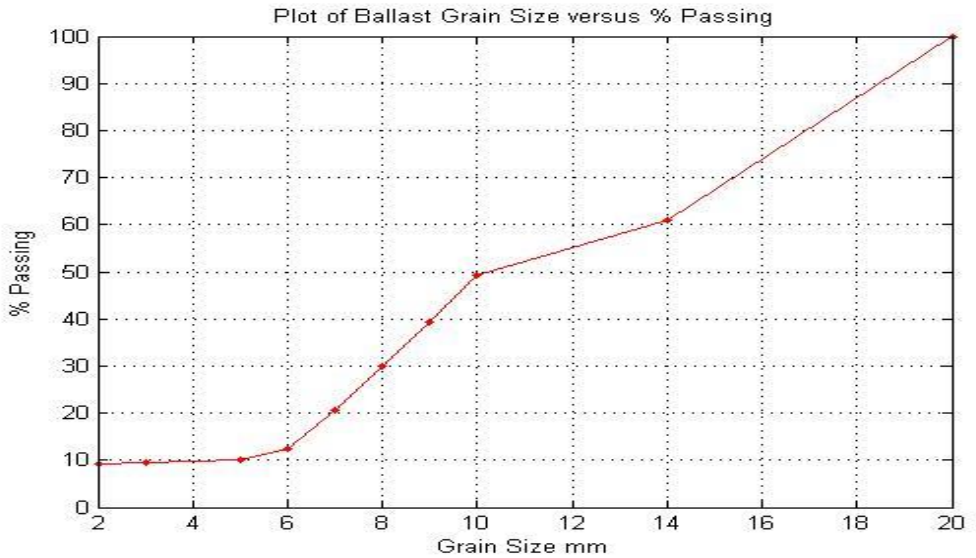

Figure 1.0 Grain size distribution of Ballast sample.

The *coefficient of uniformity*, C_u is a crude shape parameter.

$C_u = D_{60}/D_{10} = 14/2 = 7$

The *coefficient of curvature*, C_c is a shape parameter.

$C_c = (D_{30})^2 / D_{10} \times D_{60} = (8)^2 / (2 \times 14) = 7$

According to USCS, the following criteria must be met:

$C_u \geq 6$ & $1 < C_c < 3$

If both of these criteria are not met, the soil is classified as poorly graded. If both of these criteria are met, the soil is classified as well graded.

Slump Test:

Table 4.0 show the slump height of SCBA blended concrete for SCBA grain size retained sieve size 2mm, 1mm and passing 0.075mm and denoted as N_2, N_1 and $N_{<0..075}$. Each of the former was determined from the average of 3 slump tests to obtain slump heights; N1, N2 and N3. C was the control mix or 0% SCBA replacement of cement in concrete. The tabulated results shown in table 4.0 were used to develop bar chart presentations of slump height of wet concrete of SCBA grain size retained in sieve 2mm, 1mm and passing 0.75mm at cement replacement 0% (control), 5%, 10%, 15%, 20%, 25% and 30% as shown graphically in figure 2.0.

Table 4: Slump Height (mm) of Concrete at different SCBA grain size cement replacements

SCBA % Replacement	**Slump Height (mm)**											
	2				**1**				**< 0.075**			
	N1	**N2**	**N3**	**N_2**	**N1**	**N2**	**N3**	**N_1**	**N1**	**N2**	**N3**	**$N_{<0..075}$**
C	51	50	50	**50**	58	56	54	**56**	62	59	56	**59**
5	45	44	46	**44**	49	51	50	**50**	54	54	54	**54**
10	43	43	44	**43**	47	46	47	**47**	52	53	53	**53**
15	39	40	42	**40**	43	42	43	**42**	46	46	47	**46**
20	38	38	39	**38**	41	40	41	**41**	43	43	43	**43**
25	33	34	34	**34**	36	35	37	**36**	39	39	40	**39**
30	32	29	30	**31**	33	33	34	**33**	36	37	35	**36**

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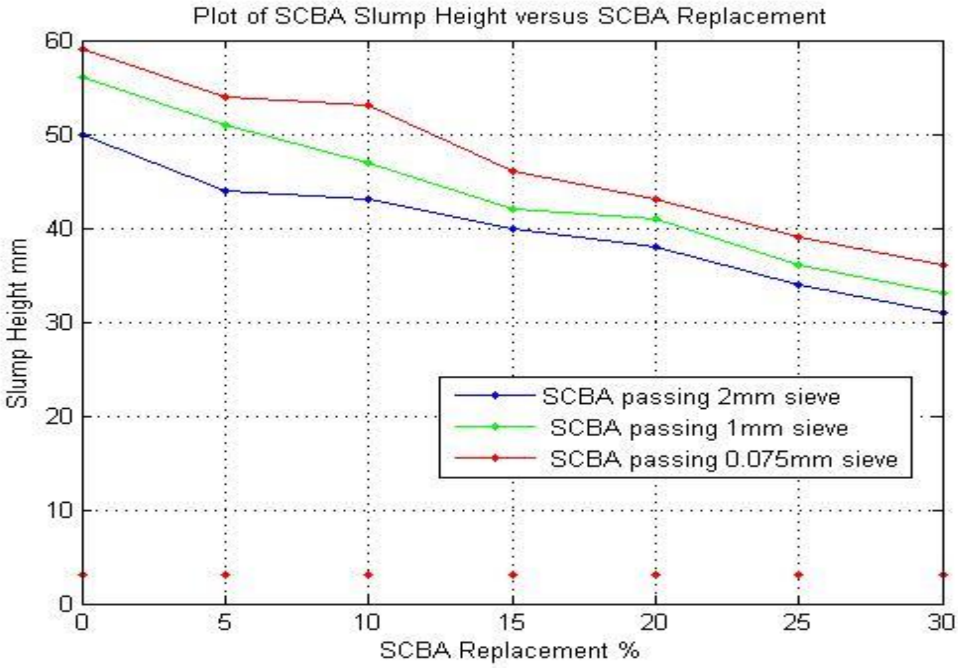

Figure: 2. Slump height of blended concrete for different SCBA grain sizes

The above results shows that the slump height of the SCBA blended concrete was higher with lesser grain size of SCBA, further, the slump height decrease with increase of SCBA replacement of cement. Similar results were obtained by [16]. As stated by [17] all of the mixes that contained SCBA required more water than the control. To maintain the desired slump flow, the amount of water needed for mixes containing SCBA was found to increase as the proportion of SCBA increased. This shows that SCBA absorbed more water than cement. This increased water requirement may be due to the porous nature of the bagasse particles, which have a larger surface area and average size leading to enhanced absorption of water. According to [18], SCBA have low fineness modulus than natural sand and hence it requires more cement paste to maintain workability.

[19] Concluded that the sharp decrease in workability was justified by the fact that the SCBA absorbs enough water needed to maintain the consistency of the concrete, leaving the later drier and, consequently, less workable. A high-quality concrete is one which has acceptable workability (95 mm slump height) in the fresh condition, basically, the bigger the measured height of slump, the better the workability will be. Increasing amount of SCBA also affects the increase of w/c ratio. SCBA tend to be hydrophilic material, therefore, its affinity to water is higher than that of cement, according to [20] and its structure as an irregular shape with porous surfaces results lot of water to confine inside the structure.

However there are other researchers whose results showed that there was increase in workability with increase in SCBA content in the blended concrete. [21] and [22] concluded that improved workability can be attributed to the low value of loss of ignition (LOI) which indicates the SCBA samples analyzed was completely burned and there was no carbon content in the ash,

Compressive Strengths Results:

Average values of concrete compressive strengths for the various curing ages (7, 14 and 28days) and percentages of OPC replacement with SCBA (0, 5, 10, 15, 20, 25 and 30%) were obtained and presented in tables and graphs. From the results above it was observed that the finest SCBA samples generate the highest pozzolanic activity and slump height, hence the remaining focus of characterization compressive strength of the blended concrete was on SCBA grain size < 0.075mm. Table 5.0 show the compressive strength of SCBA blended concrete for curing periods 7, 14 and 28 days denoted as L_{7d} , L_{14d} and L_{28d} respectively. Each of the former was determined from the average of 3 compressive strengths; L1, L2 and L3. C was the control mix or 0% SCBA replacement of cement in concrete.

Table: 5. Compressive strength of blended OPC - $D_{<0.075}$ SCDA concrete

SCBA % Replacement	Compressive Strength (N/mm²)											
	L_{7d}				L_{14d}				L_{28d}			
	L1	**L2**	**L3**	**L_{7d}**	**L1**	**L2**	**L3**	**L_{14d}**	**L1**	**L2**	**L3**	**L_{28d}**
C	15.2	15.1	15.1	**15.1**	17.2	17.1	17.0	**17.1**	22.9	23.2	23.5	**23.2**
5	15.5	15.5	15.6	**15.5**	18.3	18.0	17.5	**17.9**	23.3	23.4	23.5	**23.4**
10	15.6	15.9	15.5	**15.7**	18.4	18.2	18.0	**18.2**	24.2	24.1	24.0	**24.1**
15	9.2	9.2	9.2	**9.2**	12.5	12.5	12.4	**12.5**	16.7	16.8	16.8	**16.8**
20	7.9	8.3	8.1	**8.1**	9.5	9.0	9.3	**9.3**	13.3	13.4	13.5	**13.4**
25	5.1	4.9	4.7	**4.9**	7.2	7.2	7.1	**7.2**	9.2	8.8	8.7	**8.9**
30	3.6	3.6	3.5	**3.6**	5.4	5.4	5.5	**5.4**	7.3	7.2	7.1	**7.2**

The above tabulated results were used to develop bar chart presentations of compressive strengths of SCBA for curing periods of 7, 14 and 28 days as shown in Figure 3.0 through Matlab R2013a program application and analysis.

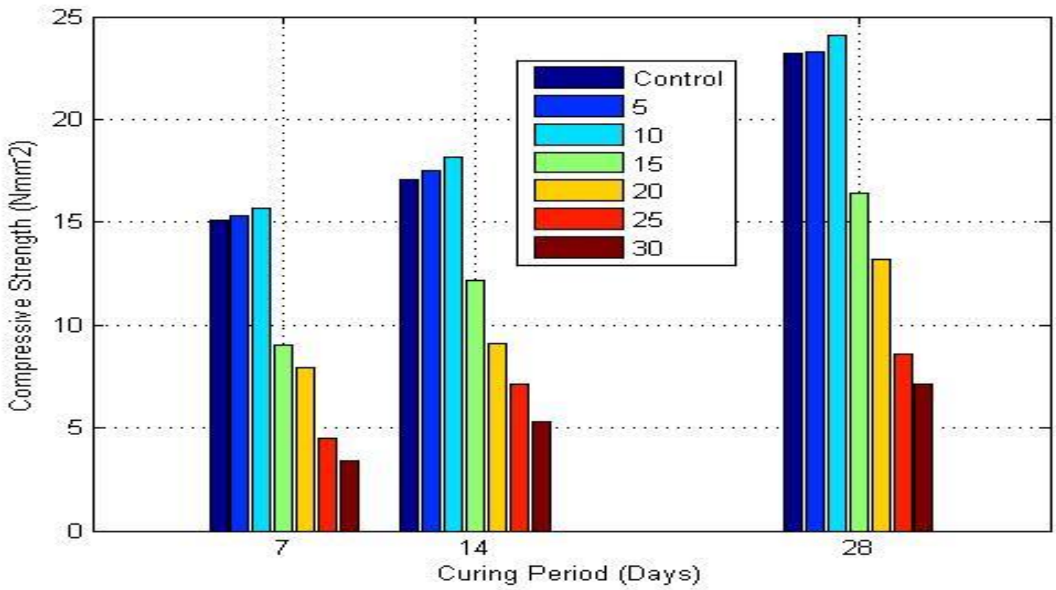

Figure: 3. Bar chart presentations of compressive strengths of SCBA for curing periods of 7, 14 and 28 days

The compressive strengths of the binary blended cement concrete produced with OPC and SCBA are shown in Table 5.0. It can be seen that there is a gradual increase in the compressive strength values of the blended concrete up-to 10% of SCBA replacement of cement than a sharp drop as the SCBA replacement increase. The bar chart representation also show a consistent rise in compressive strength of the blended concrete as the curing period is enhanced.

[23] and [24] showed the results indicate that 10% of SCBA seems to be the optimum limit but when the percentage of (SCBA) in concrete exceeded more than 10% of (SCBA), it showed decrement in the strength values. This decrement of the strength may be due to the probable SCBA cover to the surface of cement and aggregate, therefore reducing the bonding between the aggregate and cement in concrete mix. Some researchers gave almost similar results to those of this study. [25] Showed that cement could be advantageously replaced with SCBA up to maximum limit of 15%.

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It would be interesting to note that similar studies done by other researchers gave more diverse results, although there was a consensus that the compressive strength of SCBA blended concrete increased with higher curing period. [21] Established that at all ages, the blended concrete mixes containing 5, 10, 15 and 20% of SCBA showed higher compressive strength than the control mix. But, [26] showed that there was a gradual decrease in the compressive strength of concrete at 0%, 5%, 10%, 15% and 20% replacement of SCBA

5. CONCLUSIONS

This FI of the ballast sample used as course aggregate in the SCBA blended concrete was within the minimum 15% required for acceptable course aggregate to achieve durable concrete as per [11] specification**.** $C_{c \text{ and }} C_u$ of the ballast was 7 and 8 respectively hence well graded. The SCBA grain size of < 0.075mm would be the most appropriate aggregate size to provide high workability and compressive strength of the blended concrete. The optimum SCBA replacement of cement of 10% is required to give the maximum compressive strength of SCBA blended concrete, higher than a similar mix with 0% SCBA content. It was generally observed that a trend characterized the 7, 14 and 28 days curing periods, hence compressive strength of blended SCBA concrete models can be developed.

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