HIGH-Strength Concrete Production Using Sugarcane Bagasse Ash and Bama Gravel Aggregate

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ABSTRACT
This study focuses on the use of Sugarcane Bagasse Ash, Bama gravel, river sand and crushed stones of different sizes obtained in Maiduguri, Borno State of Northern Nigeria, for the production of high strength concrete. The materials were admixed with up to 20% Sugarcane Bagasse Ash (SCBA) in stepped wise increment of 5% as partial replacement for cement in the production of the concrete. Results of the analysis included, X-ray Fluorescence (XRF) analysis for the generated SCBA. The oxide composition of SCBA shows that SiO_2 (49.68), Al_2O_3 (17.34) and Fe_2O_3 (13.43) collectively yielded 80.38% which satisfied the minimum requirement of 70% recommended by (ASTM C618, 2008) for pozzolanic material. The coefficients of uniformity and curvature revealed that the river sand and Bama gravel were found to be poorly graded sand and poorly graded gravel with sand respectively based on Unified Soil Classification System (USCS). The aggregates crushing and impact values were within the permissible values of less than 30% and 35% respectively. The admixed samples cured for 1, 3, 7, 14, 21 and 28 days showed significant strength development when compared with the control sample. Out of the four dosages of 5, 10, 15 and 20% SCBA cured for 28 days, the compressive strength results revealed that the specimen admixed with 10% dosage has the optimum strength of 47.08 N/mm^2 which is 12.98% less than the control sample value of 53.19 N/mm^2. The concrete results also indicated that the slump values obtained are within the ACI specification of (25mm – 100mm). The bagasse ash used was generated using open burning method due to unavailability of controlled incinerator and CO_2 generated by bagasse during burning were ignored and 42.5 grade (42.5 N/mm^2) cement used due to unavailability of higher grades in the market.

Keywords: High-strength concrete, bagasse ash, Bama gravel, compressive strength, workability.

1.0 Introduction

Concrete is the most widely used construction material all over the world, and basically composed of two components, paste and aggregate. The paste contains cement and water and sometimes other cementitious and chemical admixtures sometimes regarded as slurry, whereas the aggregates include sand and gravel or crushed stones. The paste binds the aggregates together with inert filler materials that occupy 70 to 80% of the concrete (Vito, 2015). Concrete is next to water in terms of usage by mankind, whose production capacity exceeds that of steel by almost 30 times in volume and 10 times in mass with average global production of 6 billion tons in industrialized developing world (Johannes, 2012; Hisham, 2013).

Conventional concrete is a versatile, resistant, and durable construction material but under several physical and chemical processes as well as certain environmental conditions, can deteriorates over a short period of time (Huai, 2013). The level of deterioration is usually affecting most strength characteristics such as compression, tension and spalling etc.; depending on its resistance capacity within the ambient environmental phenomena or ecosystem of its application. Hence, the need for the development of other new types of concrete that could be eco-friendly and cost effective to overcome the above-mentioned challenges. These categories of specialised concrete include; High Strength Concrete (HSC), Ultra High Fibre Reinforced concrete (UHFRC), Ultra–High Performance Concrete (UHPC) and High-Performance Concrete (HPC). The use of these types of concrete are usually recognised as having compressive strength higher than 42 MPa (Pierre *et al.,* 2017). Apart from this, these concretes are often inspired by a high durability and longer life span through the incorporation of cementitious and chemical admixtures compared to conventional normal concrete

The production of HSC may or may not involve special materials, but it requires materials of optimum index properties. The strength values for high strength concrete usually range from 34Mpa – 51Mpa which depends on the environment, availability of the raw material and expertise required. (Osama and Sagady, 2013). Furthermore, (Lius and Maria, 2015) defines high-strength concrete as concrete with a compressive strength greater than 45 MPa. Production of high-strength concrete includes making optimal use of the basic ingredients that constitute normal-strength concrete. Recently, because of the risk of likely aggressive attack on the prestressed strands, the poser has arisen whether the use of these cementitious and chemical admixtures will adversely affect these categories of concrete being use for prestressed concrete or they are restricted only for use in reinforced concrete production.

It is also worth noting that the compressive strength is not the only criterion used to classify a material as HSC or HPC etc. For instance, a normal strength concrete with very high durability and very low permeability is considered to have high-strength properties (Sanyasinaidu and Harish, 2017). Not all properties can be achieved at the same time. Therefore, HSC specifications are purpose oriented.

Zulfequar, (2017) and M. Amin et al., (2022), observed globally that the demand for cement which is a binder known as a matrix material is increasing annually by 2.5 – 5.8%, due to the increase in demand for housing, roads and other social infrastructures since world's population is expected to increase to 8.5 billion in 2030, 9.7 billion by 2050 and 10.4 billion by 2100 (UNDESA, 2022). This consequently will lead to increase in demand for concrete which is forecasted to grow annually. Therefore, the used of raw materials from renewable natural resources is required in large quantities in order to meet this expected demand. In addition, cement and concrete industries productions has been an environmental issue since this industry contributes about 9% carbon dioxide emission worldwide along with greater consumption of energy which leads to global warming (Nik *et al.,* 2017). Thus, this endangers the sustainability of the cement industry and that of concrete. In addition to its negative environmental impact, cement is also one of the most expensive materials when compared to the other constituents of concrete. The high cost of cement, inadequacy of conventional concrete coupled with environmental problems caused by its production calls for more reliable, economically and environmentally friendly materials as alternatives or partial replacement materials for cement in concrete.

This research investigates the application of Bagasse ash and other local aggregate such as Bama gravel and crushed stone materials for the production of HSC for various applications, through the determination of the physical, mechanical and chemical properties of constituent materials of the HSC and its influence on other properties of HSC.

2.0 MATERIALS AND METHODS

2.1 Materials

The constituent materials used for the production of HSC include:

a. Cement

The cement used for this study is the Ordinary Portland Cement OPC (Grade 42.5). obtained in open market which served as the main binder.

b. Bagasse ash

The bagasse was collected from local sugarcane Market in Maiduguri, and subjected to Open burning method to convert the bagasse into ash in order to obtain fineness similar to that of Ordinary Portland cement (OPC). The availability of BA is linked to the high production of sugarcane in Nigeria which amounts to over 15 million tonnes per year out of which 25% of each kg of the sugarcane becomes bagasse after extraction of the juice *(Lathamaheswari et al., 2017)*. SCBA was generated by sieving the burnt material using 0.075mm sieve and stored in a polythene bag. The bagasse ash will be generated using open burning method due to unavailability of controlled incinerator and CO_2 generated by bagasse during burning will be disregarded since, it does not cause significant harm to the environment. As the quantity of CO_2 liberated is neutralized by CO_2 consumption during sugarcane plant growth (Jagadesh et al., 2018)

Aggregates

Three different types of aggregates used in this research were fine sand, Bama gravel and crushed stones were obtained from following sources;

- Fine aggregate was obtained from Alau River and tested for physical properties
- The coarse aggregate, locally referred to as "Bama Gravel" source from Bama-ridge which began at the Cameroon plains, and extending some 300 km northwards towards Bama and Maiduguri.
- Crushed stones of various sizes 19mm and 38.1mm were used in this research. The crush stones were subjected to sieve analysis using aperture sizes ranging from 10mm to 40mm set of sieves where these sizes were obtained.

c. Water

Running tap water was used for mixing as well as curing of the concrete

2.2 Methods

2.2.1 *Index Properties of Aggregates*

Material classification conducted in accordance with specifications outlined in British Standard (BS) 1377 (1990).

2.2.2 *Aggregate Crushing and Impact Values*

The determination of Sieve Analysis, Aggregate Crushing Value (ACV) and Aggregate Impact Value (AIV) were carried out in line with the provision of British Standard (BS) 812 part 110 of 1990 and BS 812 part 112 of 1990 and Road Note 4 (Neville, 2011) respectively.

2.2.3 *Cement and Supplementary Cementitious Material (SCM)*

Oxide composition for the bagasse ash was determined using X-ray fluorescence (XRF) analysis Cu -Zn method. The XRF analysis is based on the principle that individual atoms, when excited by external energy source, emit x-ray photons of a characteristic wavelength. One gram each of well homogenized cement and SCM will be introduced into the machine using a sampler which automatically analyse and give the results with help of elemental lamp. By counting the number of photons of each energy emitted from a sample, the elements present is identified and quantified (Ehi-Eromosele *et al.,* 2012).

2.2.4 *Concrete Mix Design*

In this study HSC mix was designed based on ACI 211-4R-93 guidelines which translate into normal concrete mix design manual (BS8112); the appropriate design mix proportion and slump that gave a suitable water-cement ratio that produced a workable consistency for the production of concrete was determined.

Due to variability of concrete in production a targeted mean strength was calculated from the characteristic strength and a margin (Teychenné, *et al.,* 1998).

$$f_m = f_c + ks$$

Where f_m = The target mean strength
f_c = The specified characteristic strength
k = A constant that reflects the defective level of the samples;
s = Standard deviation

The water cement ratio was determined from the relationship between compressive strength and free-water/cement ratio compared with the standard giving in BS 5328 dealt with workability and determined the free-water content, a maximum size of 38.1 mm and 19.0 mm crush/uncrushed aggregate and a slump of 60-180 mm was used to combined the results above and determined the cement content, total aggregate content and lastly dealt with the selection of fine and coarse aggregate contents (Teychenné, *et al.,* 1998)

2.2.5 *Production of Concrete*

The standard cubes of (150mm x 150mm x 150mm) were cast for each trial mix for compressive strength. Total of 90 cubes were produced using mix proportion of (Cement,1: Fine Aggregate 0.44: Bama Gravel 0.24: 19mm Crushed Stones 0.15: 38,1mm Crushed Stones 0.87) at 0.25 water cement ratio. The Zero percent bagasse ash serves as the control, subsequently a 5% variation were tested between 0 to 20% respectively. Mechanical mixer was used for all trial mix throughout the experiment. The concrete cubes were produced and cured for 1,3,7,14,21 and 28 days respectively. The average of three (3) concrete cubes were crushed and results reported.

3.0 RESULTS AND DISCUSSION

3.1 *Chemical Composition of Bagasse Ash*

In Table 1.0, presented is the result of the chemical analysis of sugarcane bagasse ash (SCBA) which shows that, SCBA has very high percentage of silica oxide (SiO_2), aluminium oxide (Al_2O_3) and iron oxide (Fe_2O_3). According to this investigation the amount of silica oxide contained in bagasse ash is 49.67%, aluminium oxide 17.33% and iron oxide 13.42% which complies with the pozzolanic requirements of ASTM- C618, (2000) which specifies that for a material to be considered a pozzolana, the summation of the percentages by weight of silica, alumina and ferric contents must not be less than 70%. The summation of these three constituents is 80.38%, which is greater than the 70% minimum requirement ASTM- C618. Therefore, the bagasse ash used in this study is a pozzolanic material and belongs to class F of pozzolanic classification (Wardhono, 2017).

Chemical Oxides	**Value (%)**
CuO	0.00
NiO	0.00
Fe_2O_3	13.43
MnO	0.00
Cr_2O_3	0.02
TiO_2	1.42
CaO	4.12
Al_2O_3	17.34
MgO	1.38
ZnO	0.00
SiO_2	49.68
Total	**87.38**

3.2 *Specific gravity*

The specific gravity of bagasse ash obtained is low compared with ordinary Portland cement which has specific gravity of 3.1 (Puppala and Ratnam, 2014). The result obtained shows that bagasse ash has a low specific gravity of 2,2, which is similar to the result obtained by another researcher (Amin, 2015). Hence low weight concrete is obtained, this can also be attributed to large amount of lightweight un-burnt particles in the ash (Paya *et al.,* 2002).

3.3 *Particle Size Distribution*

In Figures (1.0 and 2.0), the particle size distribution for the river sand, and curve for the Bama gravel materials gave the values of coefficient of uniformity and curvature as 1.51 and 0.27 and 2.43 and 1.17 respectively. Based on Unified Soil Classification System (USCS), the materials are classified as poorly graded sand (SP) and poorly graded gravel with sand (GP) respectively (ASTM-D2487, 2011). Hence, the poorly graded materials could lead to low inter particle bondage between the aggregates, thereby creating more void space within the concrete matrix.

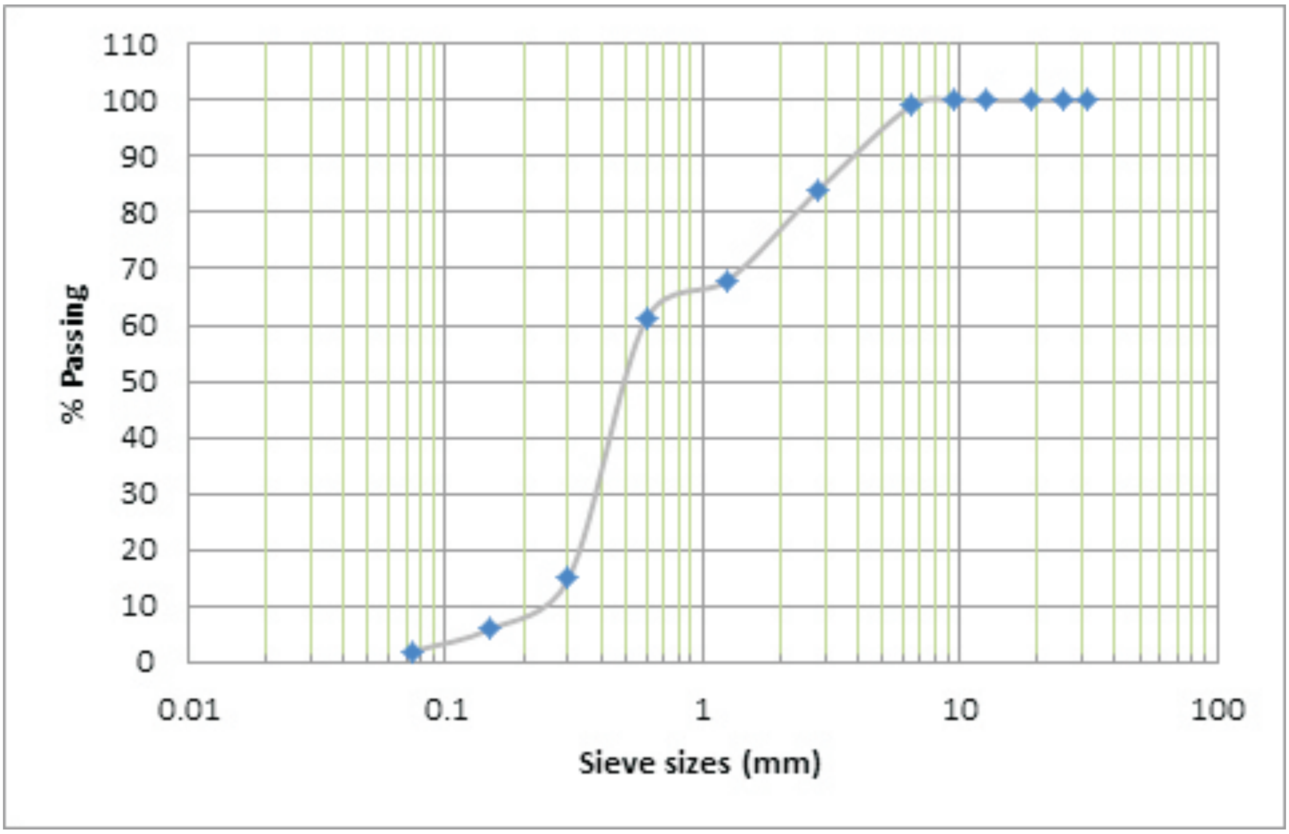

Figure 1.0: Particle size distribution for river sand material.

$$Cc = \frac{D30^2}{D60 \times D10} = \frac{0.39^2}{0.59 \times 0.25} = 0.27,\ Cu = \frac{D60}{D10} = \frac{0.59}{0.25} = 1.51$$

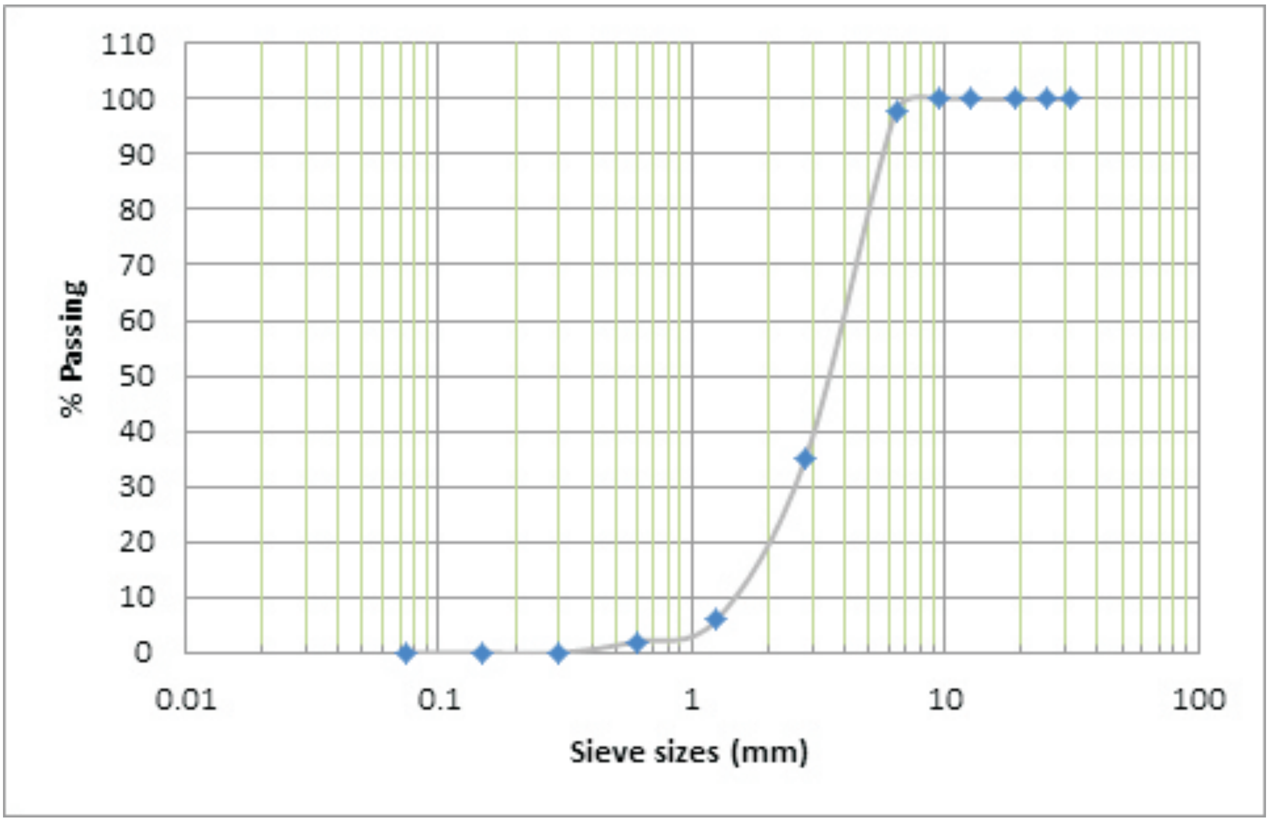

Figure 2.0: Particle size distribution of coarse aggregate

$$Cc = \frac{D30^2}{D60 \times D10} = \frac{2.7^2}{3.9 \times 1.6} = 1.17, \; Cu = \frac{D60}{D10} = \frac{3.9}{1.6} = 2.4$$

3.4 *Aggregate Crushing and Impact Values*

In Tables (2.0 and 3.0), the *Aggregates Crushing and Impact Values* (ACV and AIV) results show that both materials are within the limit of specification of ASTM D 5821 (2017) which stated that the values for aggregate crushing and impact should not exceed 30% and 35% respectively. Hence, these materials are considered good in measure of the resistance to crushing and impact under a gradually applied compressive load.

Table 2.0: ACV Result for Crushed Stone Materials

Sample	ACV%	Specification
19mm	19.67	
38mm	20.33	**=30%**
(Coarse aggregate)	26.21	

Table 3.0: AIV Result for Crushed Stone Materials ASTM D 5821 (2017)

Sample	AIV%	Specification
19mm	21.68	
38mm	23.33	**=35%**
(Coarse aggregate)	29.12	

3.5 *Workability*

A high-quality concrete is one which has acceptable workability in its fresh condition and develops sufficient strength. Basically, the higher the measured height of slump, the better the workability will be, indicating that the concrete flows easily but at the same time is free from segregation. Maximum strength of concrete is related to the workability and can only be obtained if the concrete has adequate degree of workability because of self-compacting ability. The workability of control and treated samples are presented in Table 4.0. It shows the influence of SCBA content on the workability of mixtures at constant water to binder ratio of 0.45 (water / cement ration) while that of control sample remains 0.3. The results show that unlike the Control, all investigated SCBA mixtures lead to higher slump values and acceptable workability when compared with 25 to100mm range specified as conventionally acceptable values (ACI, 1991).

Table 4.0: Workability values for High Strength Concrete

Sample designation	Water / Cement Ratio	% of SCBA	Workability (Slump; mm)
Control	0.30	0	40
S1	0.45	5	46.9
S2	0.45	10	51.9
S3	0.45	15	58.5
S4	0.45	20	62

3.6. *Compressive Strength Results*

As presented in Figure 3.0, the results obtained for all the curing periods; it was discovered that the average compressive strength increases from 0% (control) SCBA replacement up to 10%, and the trend then decreases with increase in SCBA content between 15 and 20%. The control sample has a compressive strength development values of 23.55, 37.00, 40.09, 44.09, 46.90 and 53.19 N/mm^2 for 1, 3, 7, 14, 21 and 28-days curing period respectively. For, 1day curing period values were varying from 23.55 to 22.0 N/mm^2 and 3 day values as 37.00 to 22.01 N/mm^2; while that of 7 days gave values of 40.09 to 35.45 N/mm^2; whereas, the results for 14 days gave of 44.09 to 42.00 N/mm^2; that of 21 days were 46.90 to 44.70 N/mm^2. Finally, for 28 days such as 44.63, 47.08, 46.0 and 45.20 N/mm^2 from increase in SCBA content 5 to 20% respectively. For all the SCBA dosages and curing periods, the maximum strength of 47.08 N/mm^2 was achieved at 10% SCBA whereas the control gave a maximum of 53.19 N/mm^2 at 28 days curing period.

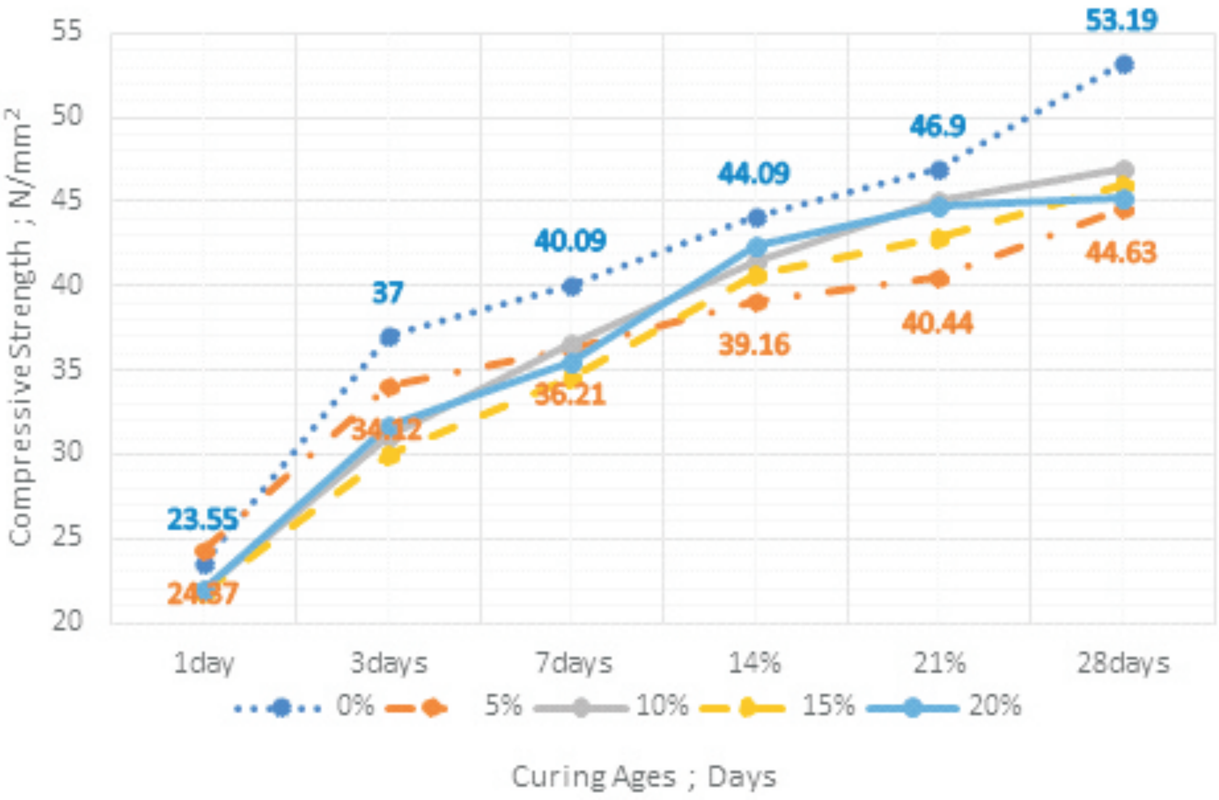

Figure 3.0: Compressive strength of High Strength Concrete with varied Bagasse Ash

4.0 CONCLUDING REMARKS AND RECOMMENDATION

i. The chemical composition of the Sugarcane bagasse ash revealed that the summation of major oxides (SiO_2+ Al_2O_3+ Fe_2O_3; i.e 13.43 + 17.34 + 49. 68 =80.34%) is 80.34% which satisfied ASTM C618 (2000) minimum value of 70% for artificial pozzolanic material; therefore, it can be inferred that open burning method is capable of achieving the desirable chemical composition of bagasse ash.

ii. In addition, the present mix proportion without the bagasse ash can adequately produce high strength concrete of compressive strength 53.19 N/mm^2 at 0.3 water cement ratio as control. However, with bagasse ash as partial replacement, 0.3 water cement ratio resulted in a harsh and an unworkable consistency; hence, an increase from 0.3 to 0.45 became necessary to produce a workable mix used for this study. The slump values for all mixes are in accordance with ACI mix design (25 - 100mm) for high strength concrete. An increase in the levels of bagasse ash consequently led to the reduction of mass or volume of total available cement in the batch; and because of the general gradual increase in the specific surface, this led to successive increase in workability and causing a gradual slight decrease in the values of the compressive strengths.

iii. A compressive strength of 47.08 N/mm^2 was achieved when using 10% of SCBA at 28 days curing period. However, the strengths gradually decreased with replacement by 15 to 20% respectively and

iv. A bagasse ash based High Strength concrete can be used as a cement replacing material towards achieving sustainable green concrete.

It is recommended that further studies on the use of SCBA in High strength concrete be investigated beyond 28 days curing period and monitoring the strength development due to pozzolanic reaction using Scanning Electron Microscopy (SEM) analysis when subjected to fire as high as 700^0 or different types of acid and various media or ecosystems that can be useful to test for the durability of the high strength concrete produced.

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