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Suitability of Bama Gravel Aggregate and Bagasse Ash for the Production of Medium-Grade Concrete

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Abstract
Improperly dumping Sugarcane Bagasse (SB) not only occupies valuable space but also causes environmental problems and health hazards. However, these issues can be largely mitigated by converting SB into ash, which can be used in the production of green concrete. To explore this potential, a study was conducted in Maiduguri, Borno State, Northern Nigeria, where Bama gravel and river sand were mixed with Sugarcane Bagasse Ash (SCBA) at varying levels (up to 20%) as partial replacements for cement. The aim was to evaluate the suitability of SCBA in producing medium-strength concrete. The chemical composition of the SCBA was determined using X-ray Fluorescence (XRF) analysis. The combined percentage of SiO_2, Fe_2O_3 and Al_2O_3 was 70.79%, which satisfies the minimum requirement of 70% for pozzolanic material. The index properties revealed that the river sand has met the standard for the American Association of State Highway and Transportation Officials AASHTO requirement making it well-graded while the coarse aggregate was poorly graded. The samples cured for 7, 14 and 28 days showed a significant strength development beyond the control sample. Out of the four dosages cured for 28 days, the compressive strength results revealed that specimen treated with 10% dosage has the highest strength of 21.20 N/mm^2. The concrete results also indicated that the initial and final setting times increased with increase in SCBA content. Two-way analysis of Variance (ANOVA) showed that bagasse ash has a statistically significant ($Fcal = 148.7 > F_{crit} = 3.83$) effect on the compressive strength of the concrete.

Keywords: *Bagasse Ash, Bama gravel, Medium-grade concrete, Compressive strength, Variance*

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1. Introduction

Concrete is the dominant choice in the construction of buildings, hydraulic structures, and roads due to its widespread reliance on factors like cost-effectiveness, ease of shaping, and durability (Olubajo et al., 2020). It primarily comprises two essential elements, namely paste and aggregate. The paste, composed of cement, water, and sometimes additional cementitious and chemical admixtures, serves to unite the aggregate components, which consist of materials like sand, gravel, or crushed stone. These aggregates, typically making up 70 to 80% of the concrete, act as relatively inert filler materials. Consequently, the characteristics of concrete are significantly shaped by the properties of these aggregates (Vito, 2015).

The precise ratios of these components, including the aggregate, are meticulously controlled to attain specific characteristics, such as strength, workability of fresh concrete, and cost-efficiency. Moreover, the calibre of aggregates, encompassing attributes like shape, texture, and grading, exerts a pivotal influence on both the physical and mechanical properties of both fresh and set concrete (Onundi et al., 2018). Ordinary Portland cement (OPC) is acknowledged as a primary global construction material. Presently, researchers worldwide are directing their efforts toward exploring the utilization of industrial or agricultural waste as alternative raw materials for industry (Srinivasan and Sathiya, 2017). This innovative approach not only promises economic advantages but also the potential for generating foreign exchange and controlling environmental pollution. Industrial waste materials, such as blast furnace slag, fly ash, silica fume, and agricultural by-products, are being harnessed as supplementary replacements for cement. Nevertheless, it's important to note that cement production stands out as a costly and environmentally taxing process. Thus, there arises a pressing demand for more economical and environmentally friendly materials for cementing (Waziri et al., 2020).

The strength of concrete is usually depending on water-cement ratio, slump, type and quality of cement, mixing time, mix ratio, and curing efficiency index properties of aggregates (Kabir, 2010). There are basically three types of concrete, namely low strength concrete, medium strength concrete and high strength concrete which is based on their compressive strength. The medium grade concrete can be defined as concrete having compressive strength between 20 Mpa – 40 Mpa at 28 days curing period (Brabha et al., 2015).

Despite the wide acceptance and the use of only cement in concrete production due mainly to its strength, durability, and workability, cement production poses a serious environmental concern over the years (Zulfequar, 2017). During the production of cement, carbon dioxide (CO_2) is emitted as a by-product clinker in which calcium carbonate ($CaCO_3$) is calcinated and converted to lime (CaO), the primary component of cement (Prandey, 2018).

Sugarcane bagasse (SCB) is the agro – by product produced after juice extraction from sugarcane, either by milling the cane for sugar and alcohol production or chewing by individuals. It is reported that 1kg of sugarcane produces 25% of bagasse and 0.6% of ash (Nik et al; 2017). This research investigates the suitability of Bagasse ash and local aggregate known as Bama gravel for the production of medium grade concrete through the determination of their physical, mechanical and chemical properties.

2. Materials and methods

2.1 Materials

1. *Cement*

The cement used in this study was Ordinary Portland Cement OPC, grade 42.5, obtained in an open market, Maiduguri. This was used as the main binder in this study.

2. *Bagasse ash*

The bagasse used in this study was sourced from Gamboru market at custom area in Jare Local Government Area, Borno State

3. *Aggregates*

Two types of aggregates used in this research were fine aggregate (Alau River sand) and coarse aggregate (Bama gravel). Particle size distribution tests were carried out to identify their index properties as per AASHTO (1986).

4. *Water*

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

2.2 Methods

2.2.1 *Preparation of bagasse ash*

Open burning method was used for incinerating the bagasse due to unavailability of control method. The bagasse was burnt in an open metal drum of 1 m height and 0.5 m diameter with 10 mm diameter holes created around the drum for aeration and effective decomposition of the solid waste. Open burning took place for 24 hours to produce greyish ash with an average degree of fineness. The ash was collected, pounded and sieved through BS standard sieve size of 75µm in order to obtain fineness similar to that of Ordinary Portland cement (OPC) as recommended by ASTM (2008) and about 10ml of the ash was taken using small plastic container for chemical test.

2.2.2 *Oxide composition of bagasse ash*

Oxide composition of Bagasse Ash (BA) was determined using X-ray fluorescence (XRF) analysis. The XRF machine with the use of Philips PW 2400 has a very sensitive and accurate power of determining trace and major elements in both geologic and biological samples. X-rays produced by the source irradiate sample and the element present in the sample emits fluorescent X-ray radiation with discrete energies that are characteristic of the elements in the sample.

2.2.3 *Index properties of aggregates*

The following properties were determine based on the procedure stipulated by B S 1377: 1990

i. Moisture content: this is a process of determine the amount of water present in aggregates expressed as percentage of the mass of dry aggregates.
ii. Bulk density: the bulk density or unit weight of an aggregate is the mass or weight of the aggregate that required to fill a container of a specified unit volume
iii. Particle size distribution: This test is primarily used to determine the grading of materials proposed for use as aggregates or being used as aggregates. The results are used to determine compliance with the particle size distribution with application specification requirements and to provide necessary data for the control of the production of various

aggregate products and mixtures containing aggregates

iv. Specific gravity: is the ratio of weight of a given volume of aggregate to the weight of an equal volume of water.

v. Fineness modulus: fineness modulus of an aggregate represents the average size of the particles in the aggregate by an index number. It is calculated by performing sieve analysis with standard sieve.

2.2.4 Concrete production

Sugarcane bagasse ash, Ordinary Portland cement, fine and coarse aggregates were used in producing concrete using a mould size of 150mm×150mm×150mm. The nominal mix of 1:2:4, water cement ratio of 0.5 and batching by weight were used. The quantity of cement required to produce the concrete was partially replaced with SCBA at 5%, 10%, 15%, and 20% incremental rate. The mould was filled with fresh concrete compacted in three layers tapped with a tamping rod for 27times before another layer was added. A total of 45 cubes were produced for the curing ages of 7, 14 and 28 days respectively (i.e. 9 cubes for each curing period per dosage). Compressive strength test was conducted using a digital display pressure testing machine of YES - 2000 model.

3. Results and discussion

The chemical analysis of sugarcane bagasse ash (SCBA) reveals a high percentage of silica oxide (SiO_2), aluminum oxide (Al_2O_3), and iron oxide (Fe_2O_3). The investigated SCBA meets the pozzolanic requirements specified by ASTM-C618 (2008), indicating its suitability for pozzolanic use in concrete production.

The particle size distribution (PSD) of fine and coarse aggregates, characterized by D_{10}, D_{30}, and D_{60} percentages passing, indicates well-graded fine aggregate and poorly-graded coarse aggregate. The specific gravity of SCBA is lower than ordinary Portland cement, resulting in low-weight concrete. The setting time of SCBA concrete increases with SCBA content but within limits specified by BS 12:1996. The workability of SCBA mixtures at a constant water-to-binder ratio of 0.6 shows higher slump values compared to the control, attributed to increased surface area after adding SCBA.

The result of the chemical analysis of sugarcane bagasse is presented in Fig. 1 shows that SCBA has a 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 40.54%, aluminium oxide 22.59% and iron oxide 7% meets the pozzolanic requirements as per ASTM- C618 (2008) 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 sum obtained for these three constituents is 70.792%, which is greater than the minimum requirement. Thus, the bagasse ash used in this study is a pozzolanic material and belongs to class F of the pozzolanic classification (Wardhono, 2017). The result of particle size Distribution (PSD) analysis of the fine and coarse aggregates are presented in Fig. 2 and 3 respectively.

The particle size distribution (PSD) at 10% (D_{10}), 30% (D_{30}) and 60% (D_{60}) percentage passing are 0.13mm, 0.35mm, and 0.9mm respectively for fine aggregate. Similarly, the effective size at 10% (D_{10}), 30% (D_{30}) and 60% (D_{60}) percentage passing are 3.8mm, 2.36mm and 1.12mm respectively for coarse aggregate. The coefficient of curvature (Cc) and the coefficient of uniformity (Cu) for fine aggregates were estimated to be 1.05 and 6.92, and 1.3 and 3.4 for coarse aggregates. This result revealed that the fine aggregate satisfied ASHTO requirement of $1<Cc<3$ and $Cu \geq 6$ for aggregates, hence, it is classified as well-graded soil, while the coarse aggregate did not meet the requirement as $Cu<6$, thus it is a poorly graded soil. Hence, the poorly graded materials could lead to low inter particle bondage between the aggregate, thereby creating more void space within the concrete matrix.

The specific gravity of bagasse ash obtained is low compared with ordinary Portland cement which has a specific gravity of 3.1 (Puppala and Ratnam, 2014). The result obtained shows that bagasse ash has a low specific gravity of 1.8, which is the same result obtained in the research by Amin, (2015). Hence low weight concrete is obtained. This can also be attributed to the large amount of lightweight un-burnt particles in the ash.

The setting time of SCBA concrete was found to be increasing with the addition of SCBA content. The initial and final setting times were 176 minutes and 280 minutes respectively. However, this retardation was within limits as specified by BS 12:1996. Consequently, Safiuddin (2011) depicts that due to the pozzolanic reaction between SCBA and calcium hydroxide evolved from cement hydration and this cause the retardation. This could also be attributed to the porous SCBA particles which absorb more water thereby slowing the setting time.

The workability of Control and samples are presented in Table 2. The table shows the influence of SCBA content on the workability of mixtures at a constant water-to-binder ratio of 0.6 (water/cement ratio). The results show that, unlike the Control series, all investigated SCBA mixtures had high slump values and acceptable workability. This may be due to the increase in the surface area of sugarcane ash after adding SCBA which needs less water to wet the cement particles.

From the analysis of the results obtained for all the curing periods, the average compressive strength increases from 0% (i.e. control) SCBA replacement up to 10% SCBA replacement. It then decreases with an increase in SCBA content. The control sample has a strength development of 13.45, 15.20, and 19.90 N/mm^2 for 7, 14 and 28-day curing periods respectively. The values of compressive strength of concrete treated with 5%, 10%, 15% and 20% cured for 7 days were 13.9, 14.65, 10.55 and 9.60 N/mm^2 respectively, while that of 14 days revealed 15.45, 16.10, 11.20 and 10.80 N/mm^2 respectively. The results for 28 days curing period show the same pattern with values of 20.75, 21.20, 16.10 and 15.00 N/mm^2 respectively. For all the SCBA dosages and curing periods, the maximum strengths were obtained at 10% SCBA with the highest compressive strength at 28 days.

The two-way analysis of Variance (ANOVA) of the bagasse ash replacement (Fcal= 148.7> F_{crit} = 3.83) in the matrix is statistically significant and so also the curing age (F_{cal}= 408.2> F_{crit} = 4.45). The reason for the early compressive strength development of bagasse ash concrete and the increase in compressive strength up to 10% cement replacement with bagasse ash was due to silica content, fineness, specific surface area, degree of reactivity of bagasse ash and pozzolanic reaction between calcium hydroxide and reactive silica in bagasse ash in the alkaline environment as reported by previous works (Amin, 2011).

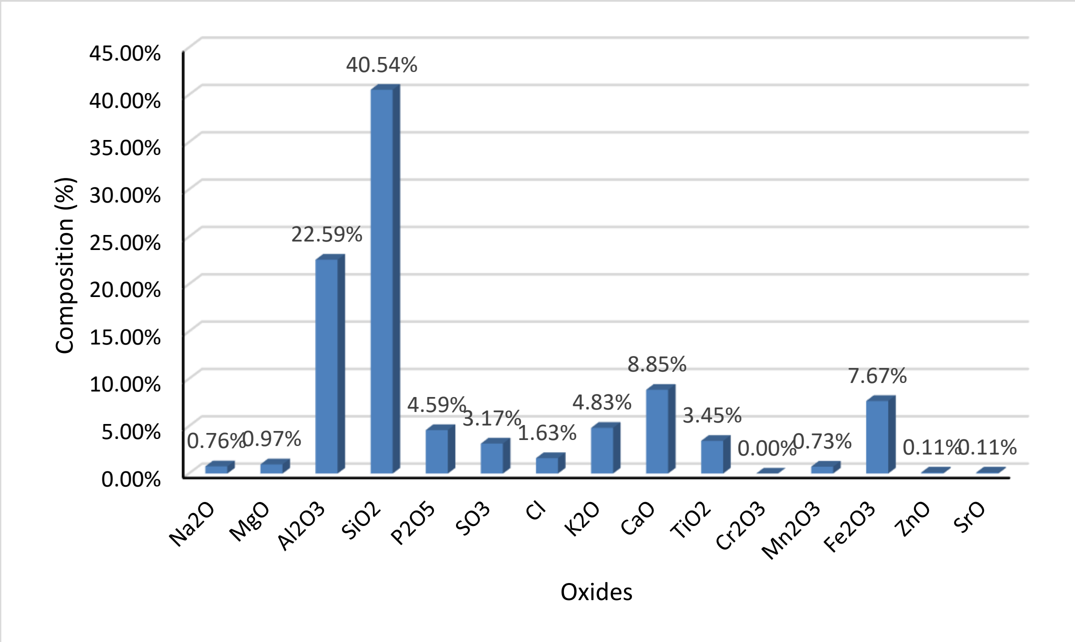

Fig 1: Chemical composition of bagasse ash

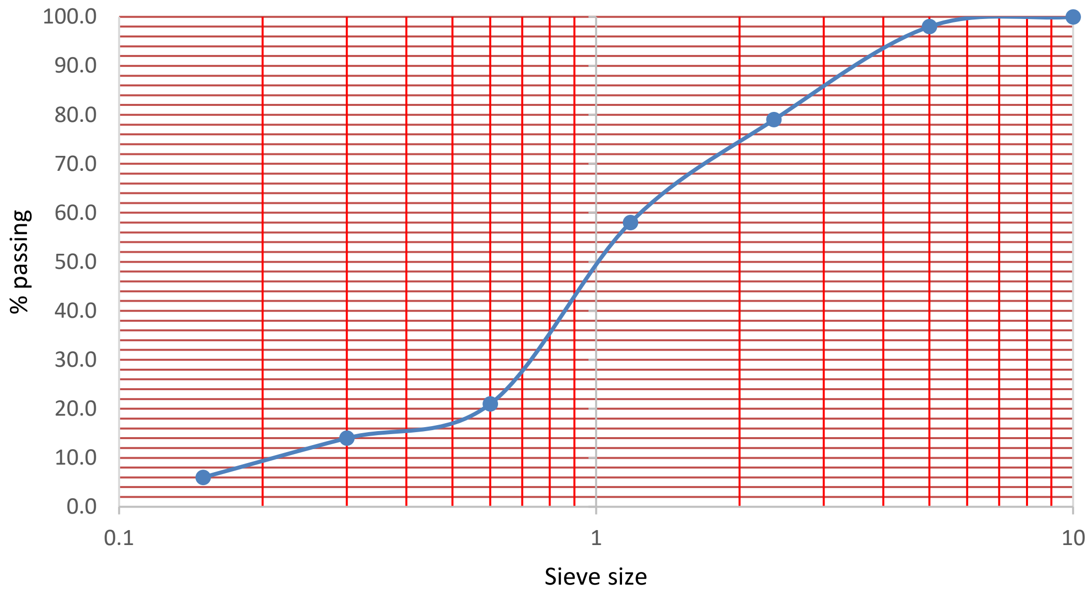

Fig 2: Particle size distribution analysis of fine aggregate

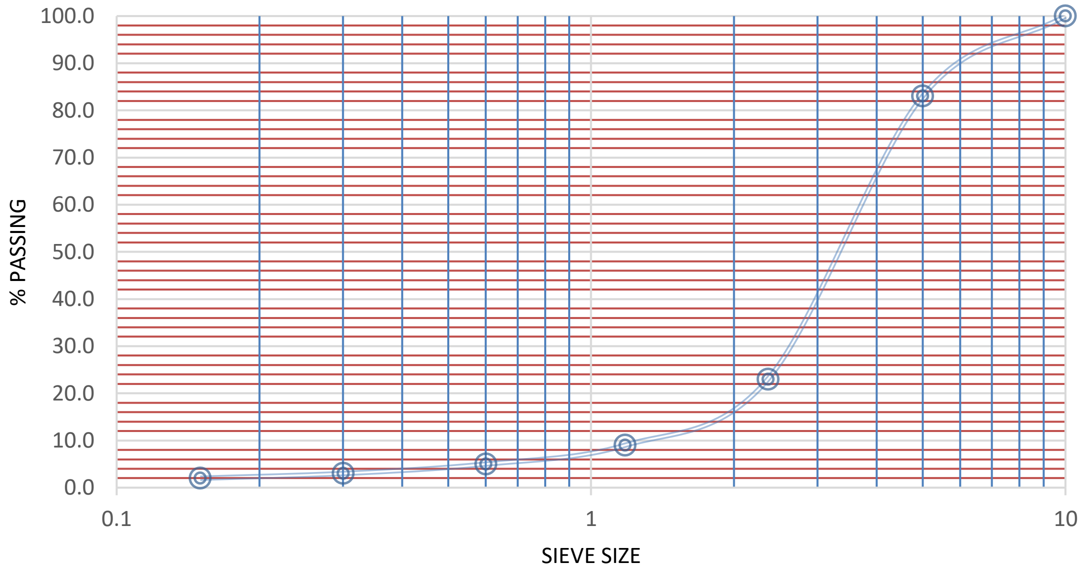

Fig. 3: Particle size distribution analysis of coarse aggregate

Table 1: Setting time values for the Bagasse Ash Concrete (SBAC)

Sample Designation	% of SCBA	Initial setting time (Minutes)	Final setting time (Minutes)
S0	0	126	280
S05	5	155	316
S10	10	183	324
S15	15	210	327
S20	20	221	325

Table 2: Workability values for the Sugarcane Bagasse Ash Concrete (SBAC)

Sample designation	% of SCBA	Workability (mm)
Control	0	32
S1	5	45.5
S2	10	52
S3	15	56
S4	20	61

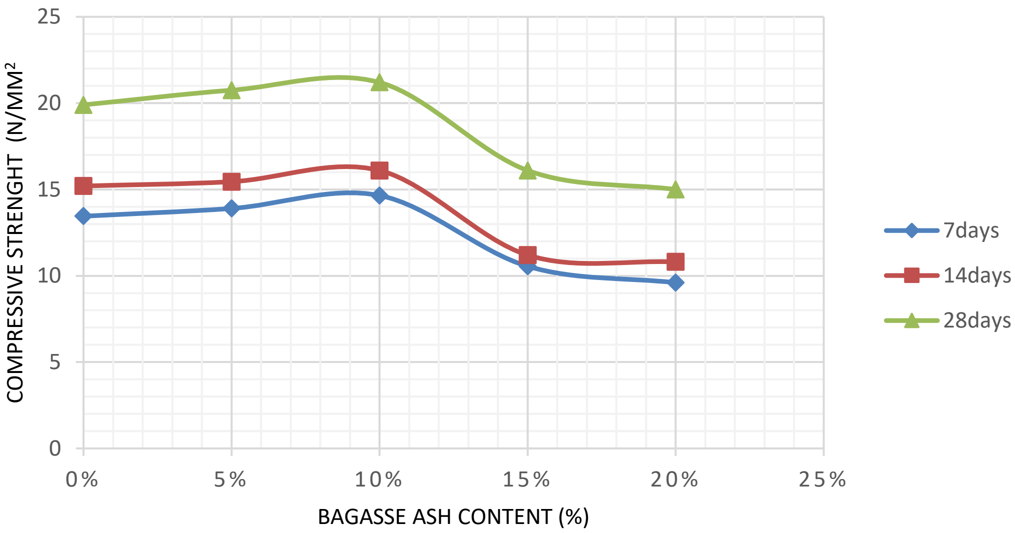

Fig. 4: Compressive strength of bagasse ash concrete (SBAC)

Table 3: ANOVA on the effect of bagasse ash on concrete strength

ANOVA						
Source of Variation	**SS**	**Df**	**MS**	**F**	**P-value**	**F crit**
Rows	105.1893	2	52.5946667	408.238034	8.86437E-09	4.45897
Columns	76.64433	4	19.1610833	148.727684	1.5335E-07	3.837853
Error	1.030667	8	0.12883333			
Total	182.8643	14				

4. Conclusion

Based on the findings of this study, the following conclusions were made:

i. The chemical composition analysis of bagasse ash indicated that the total content of major oxides (SiO_2 + Al_2O_3 + Fe_2O_3) exceeds 70%, thus meeting the minimum requirement of 70% set by ASTM C618(2000) for artificial pozzolanic materials.

ii. A compressive strength of 21.20 N/mm^2 was achieved at 10% SCBA at 28 days curing period which falls within the strength range of 20 N/mm^2 to 40 N/mm^2 for medium strength concrete. However, the strength decreases with the addition of greater than 10% SCBA.

iii. The results of the two-way analysis of Variance (ANOVA) support the finding that bagasse ash has a statistically significant impact on the compressive strength of the concrete.

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