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STRENGTH-DURABILITY PROPERTIES AND MICROSTRUCTURAL ANALYSIS OF CONCRETE CONTAINING COW BONE ASH AND BENTONITE

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ABSTRACT

One of the major agricultural wastes discarded from abattoirs in large quantities is the cow bone. Thus, there is need to find alternative means of promoting cleaner environment which is critical for environmental sustainability. This study aims to establish the viability of using cow bone ash and bentonite as partial replacement for cement improve the properties of concrete. Chemical composition examined on the CBA and BT showed that the materials have potential to serve as supplementary cementing material in concrete. In this study cement was partially replaced with cow bone ash and bentonite at 5% interval from 5 – 20%. Mix with 10% CBA/BT had the highest compressive strength across all curing ages. At 7, 14, 21, 28 and 56days 10% CBA/BT replacement recorded a 1, 49, 23, 14 and 8% increase in compressive strength respectively, similar flexural and split tensile strength examined also showed increase in strength. Water absorption test recorded a decrease in water absorption as the CBA/BT content increased. Acid resistance test showed that the concrete specimen reduced in compressive strength of at an average of 39%. The microstructure analysis of the concrete specimen revealed an improved micro packing of aggregate resulting in a denser and increased strength of concrete. The study finds that at optimal dosage of 10% CBA/BT, the concrete had an improved mechanical strength, lower water absorption ability and a better interlocking particle arrangement at microstructural level.

Keywords: Bentonite, Cement, Compressive Strength, Concrete, Cow Bone Ash, Microstructure

INTRODUCTION

Concrete is a heterogamous material consisting of fine, coarse aggregate, water and cement as the main binder (Hassan, 2015). Concrete remains the most used construction material in the world mainly due to its availability, ability to conform to any desired shape, strength and durability. Construction industry is one of the major drivers of a nation's economic growth and development. The continuous use and dependence on cement around the world as a binder in concrete has led to sustained pressure on manufacturers of cement to increase the global output of cement annually, according to world cement association conference the total output of cement is expected to be about 4215 Metric tons from 2018 to 2030. However, cement production is not an environmentally friendly process because it is associated with high pollution rate, and study has shown that it contributes about 0.815 to 1.0 tons of this effect to the environment. That is to say, for each ton of cement produced same amount of CO_2 is emitted to the atmosphere (Yeung, 2003). Many studies have been done on improvements of the engineering properties of concrete using an eco-friendly and sustainable materials. One of such material is the pozozolan. ASTM C125 (2021) in their definition of pozzolan called it a siliceous or an aluminous and siliceous material which in its natural state possesses little or no cementitious nature , but will in the presence of moisture and a finely divided form, which on reaction with calcium hydroxide at room temperature will form compounds that cementitious in nature. Most pozzolans can be found in agricultural or industrials by-products. In Nigeria there are abundant agricultural and industrial by-products waste these waste materials are disposed of as landfill. There is a growing concern to turn these waste materials into useful products that helps alleviate disposal problems and also has economic, ecological and energy saving merits. Researchers are currently looking for the best supplementary cementitious materials to partially replace conventional cement in a bid to reduce the over-dependence on industrially manufactured Portland limestone cement which has limited the construction of low cost concrete-based structures in Nigeria. A substantial amount of experimental studies has been conducted on the use of agricultural and industrial wastes as a single supplementary cementations materials. However there is limited or insufficient experimental data available for studies of ternary blend of supplementary cementitious materials. This study aims at examining the properties of concrete blended with cow bone ash and bentonite.

MATERIALS AND METHODS

Materials

Materials used in this study are;

Cement

Cement used for this study is grade 42.5. It was sourced from sourced from Albabello Trading Company Limited, Sabon Gari Zaria.

Cow Bone Ash

The cow bone ash was sourced from central meat market at Sabon Gari, Zaria. The bones were washed, dried, burnt and calcined at 800^{O}C for 3hours and allowed to cool for 24hours. The calcinated bones were grinded and sieved using sieve BS No 200 (*75*µm).

Bentonite

The bentonite was sourced from Kano Clay Factory.

Water

Portable water in compliance with standard specification of BS EN 1008 was sourced from concrete materials laboratory Civil Engineering Department Laboratory of Ahmadu Bello University, Zaria

Aggregates

Aggregates was obtained in Zaria at Abdulkarri Quarry Company opposite school of aviation at Kaduna-Kastina road.

Methods

Test on aggregates are as follows;

(i) Silt content in accordance with ASTM D2974-20, (2020)
(ii) Sieve Analysis Test for Fine and Coarse Aggregate in accordance with ASTM C136/C136M-19, (2019)
(iii) Aggregate crushing value in accordance with ASTM C131/C131M-20 (2020)
(iv) Aggregate impact value in accordance with ASTM C131/C131M-20 (2020)
(v) Specific Gravity in accordance with ASTM C127-15, (2015) and ASTM C128-15, (2015).

Test on Cow Bone Ash and Bentonite

(i) Chemical Composition in accordance with ASTM E1621-13, (2013)
(ii) Particle Size Distribution of Aggregate in accordance with BS EN 933-1 (2012)

Test on fresh Concrete are as follows

(i) Consistency Test as described in BS 196-3 (2016)
(ii) Initial and Final Setting Time Test in accordance with BS EN 195-3 (2016)
(iii) Soundness Test in accordance with BS EN 196-3 (2016).
(iv) Workability Test carried out per BS EN 206-1 (2021)

Test on Hardened Concrete are as follows

(i) Compressive Strength Test as described in BS 8500 (2019)
(ii) Flexural Strength Test conducted per ASTM C496-96 (2017).
(iii) Split Tensile Strength Test conducted per ASTM C496-96 (2017).
(iv) Water Absorption Test in accordance with ASTM C1585-20 (2020).
(v) Acid Resistant Test in accordance with ASTM C1898-20 (2020).
(vi) Scanning Electron Microscopy in accordance with ASTM E986-04, (2017).

Mix Design

The mix ratio used for this study was 1:2:4 in accordance to Council for Regulation of Engineering in Nigeria (COREN 2017). A grade 25 concrete was designed using the weight of cement with cow bone ash and bentonite from 0 to 20% at 5% interval replacement. Table 1 reveals the proportion of concrete used in this study

Table 1: Proportion material used for producing concrete cubes (100× 100 x 100mm)

S/no	Description	Water (kg)	Cement (kg)	CBA (kg)	BT (kg)	Fine aggregate (kg)	Coarse aggregate (kg)
1	CBA0%BT0%	3.03	6.045	0.000	0.000	10.08	19.16
2	CBA5%BT5%	3.03	5.441	0.302	0.302	10.08	19.16
3	CBA10% BT10%	3.03	4.836	0.605	0.605	10.08	19.16
4	CBA15% BT15%	3.03	4.232	0.907	0.907	10.08	19.16
5	CBA20% BT20%	3.03	3.627	1.209	1.209	10.08	19.16

RESULTS AND DISCUSSION

Result on Silt Content of fine aggregate

It necessary to determine the quantity of silt in natural aggregate as silt content can affect the compressive strength of concrete. Nigerian Standards Organization specifies that silt content in aggregate for concrete should be ≤ 8% otherwise the aggregate should be considered as unsuitable for concrete production. However on the other hand ASTM C117 (2017) is more lenient on the percentage of silt content on aggregate, it specifies that silt content should ≤ 10%. The silt content value obtained for the purpose of this study is shown in Table 2. The result is within the limit specified by both standards and hence considered good for concrete production. Similar results were also obtained by Olanitori and Olotuah (2005}

Table 2: Silt Content Results after 3hours

	1 (ml)	2 (ml)	3 (ml)	Average (ml)	BS Code	Code Specification
Silt (V_1)	3.8	4.2	3.9	3.97	ASTM C117 (2017)	≤ 10
Silt (V_2)	96.2	95.8	96.1	96.03		

Result on Test on Physical Properties of Cement

Test such as soundness, initial and final setting time, consistency, fineness, specific gravity was carried out in accordance with relevant standard and presented in Table 3 shows the results of average three determination preliminary test done on the neat cement with comparison with code specification. From the results in Table 3, it could be deduced that the physical properties of cement satisfactorily meet the specifications for a cement to be used in the production of concrete. Similar results were reported by Lawan *et al* (2021)

Table 3: Physical Properties of the OPC with Standard Requirement

Cement	Test Value	BS Code	Code Specification	
			Min	Max
Specific gravity	3.13	BS EN 1097-3 (1998)	2.6	3.15
Fineness test (%)	3	BS EN 196-2 (2016)	≤10	-
Soundness	1mm	BS EN 196-3 (2016)	-	10
Consistency	30%	BS EN 196-3 (2016	26	33
Initial setting time	96mins	BS EN 196-3 (2016)	45mins	600mins
Final setting time	223min			

Result on Particle Size Distribution of Aggregate (Sieve Analysis)

The particle size distribution was done to determine the gradation of aggregate and often times referred to as sieve analysis. The particle size distribution test result for fine and coarse aggregate is presented in Figure 1. The test was carried out in accordance to BS EN 933-1 (2012) and the aggregate was found to fall within zone 2 in accordance with BS EN 12620 (2008) classifications. The particle size distribution graph is shown in Figure 1. This shows that the fine aggregate is good for the production of concrete. Musa (2017) reported similar trend.

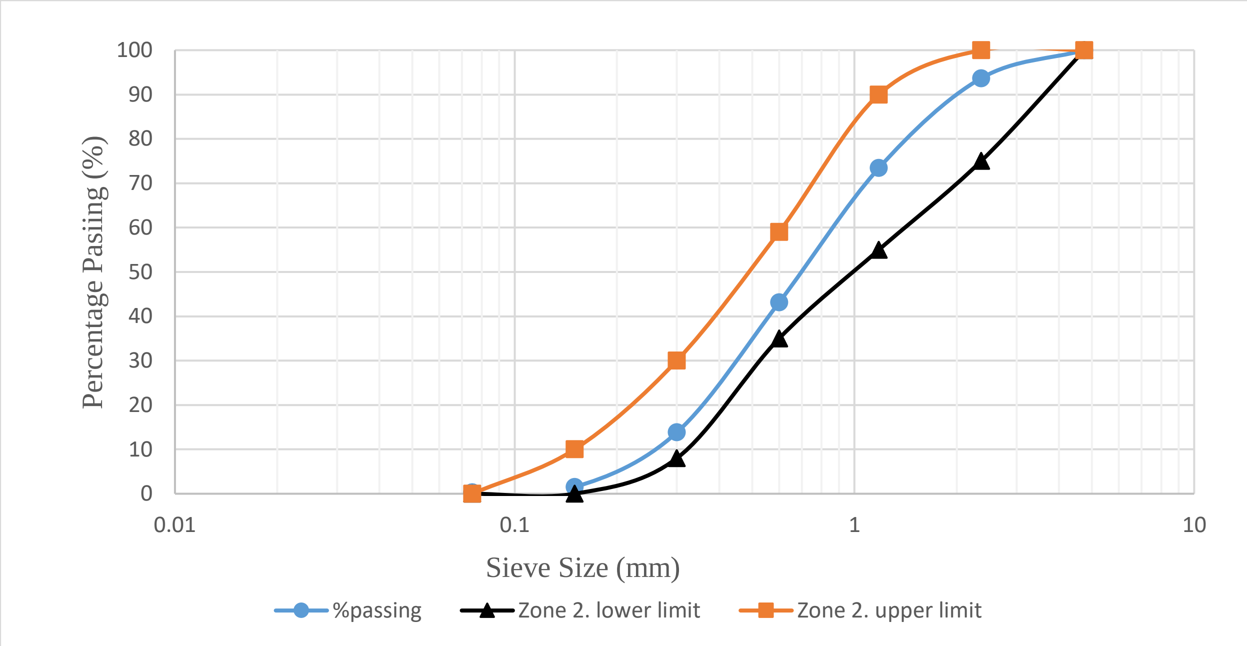

Figure 1: Particle Size Distribution of Combined Aggregate

Result on Coarse Aggregates

The results of average three determination preliminary test carried out on fine and coarse aggregate with comparison with code specification ate presented in Table 4. Test such as specific gravity, impact value, crushing value was done in accordance with relevant standard. From table 2, the aggregates satisfy the code specification requirement of toughness, strength, density and hence can be used for the production of concrete. Similar results were obtained by Shuaibu *et al*. (2021)

Table 4: Results of Physical Properties of the Fine and Coarse Aggregate

Test Conducted	ASTM/BS Code	Test Results	Code Specification	
			Min	Max
Specific gravity	ASTM C127 (2005)	2.78	2.4	3.0
Impact Value (%)	BS 812 part111 (1990)	18.06%	-	30
Crushing Value (%)	BS 812 part112 (1990)	17.2%	-	30

Results on Chemical composition of Cow Bone Ash (CBA) and Bentonite (BT)

The chemical characterization of CBA and BT was done using X-Ray fluorescence (XRF) to establish the chemical composition of the materials. This test is necessary for elemental analysis and for understanding of the material integration in the ternary blend of concrete and the role each oxide plays in the hydration process and concrete strength development. The results for CBA and BT are presented at Table 5. According to ASTM C-168-19 (2019) Standard, both CBA and BT materials can be classified as Class F pozzolana as the combination of SiO_2 + Al_2O_3 + Fe_2O ≥ 70%, also SO_3 ≤ 5 and LOI ≤ 6. However it is worthwhile to note that cow bone ash is rich in CaO content (66.34%) and low in SiO_2 (9.57%) while bentonite has abundance of SiO_2 (56.81%) and low in CaO content (6.02%), these mentioned oxides plays a major role in cement concrete matrix bonding and strength. Tsado *et al* (2018); Karthikeyan *et al* (2015) obtained similar result.

Table 5: Chemical Composition of Cow Bone Ash (CBA) and Bentonite (BT)

Oxide Composition	CBA Content (%)	BT Content (%)	BS EN 196-2 (2016) Recommendation
CaO	66.34	6.02	Limit not specified
SiO_2	9.57	56.81	Limit not specified
Al_2O_3	7.14	5.45	Max. 6.0%
Fe_2O_3	0.18	5.89	Max. 6.0%
MgO	1.17	2.08	Max.6.0%
SO_3	0.88	1.33	Max. 4.5%

K_2O	0.11	2.01	Limit not specified
LOI	0.47	3.79	Max. 5.0%

Result on Consistency of Cement-Paste

The consistency of cement paste (the mixture of CBA and BT as a replacement of part of cement) was carried out according to BS EN 196-3 (2016) and the results was presented in Figure 2. The results showed that increase in quantity of cow bone ash and bentonite in the paste, there was a corresponding increase in water content required to achieve standard consistency. This is due to the high-water affinity behaviuor exhibited by bentonite and cow bone ash.

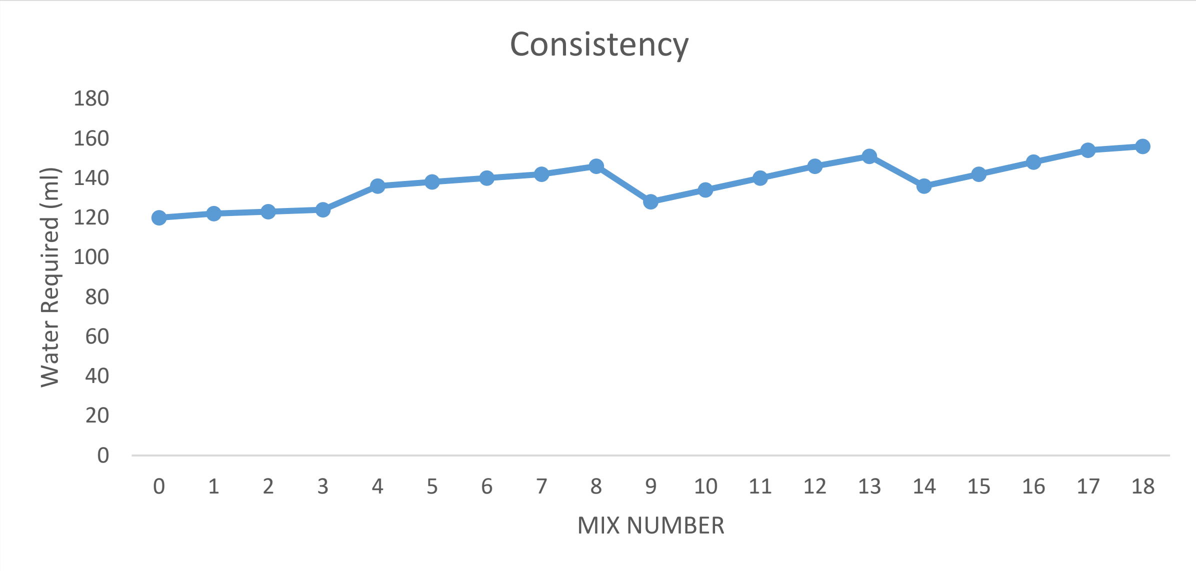

Figure 2: Consistency of Cement-CBA-BT Paste

Result on Initial and Final Setting time of Cement-CBA-BT Paste

The results of the initial and final setting time of cement and paste are shown in Figure 3. Addition of CBA and BT to cement paste caused a reduction in the initial and final setting time Givi *et al* (2011) explained that, the setting time reduction could be due to the reaction between impurities from the pozzolans and CaO, Al_2O_3 and SiO_2. Another plausible explanation for the reduction in setting time reduced quantity of tricalcium silicate (C_3S), thereby leading to the reduction of silicate compound responsible for hydration of the cement paste. The different value of setting time obtained from the cemnt CBA-BT paste are within the limits set by BS EN 196-3(2016). This is similar to the results reported by Haruna and Adamu (2020).

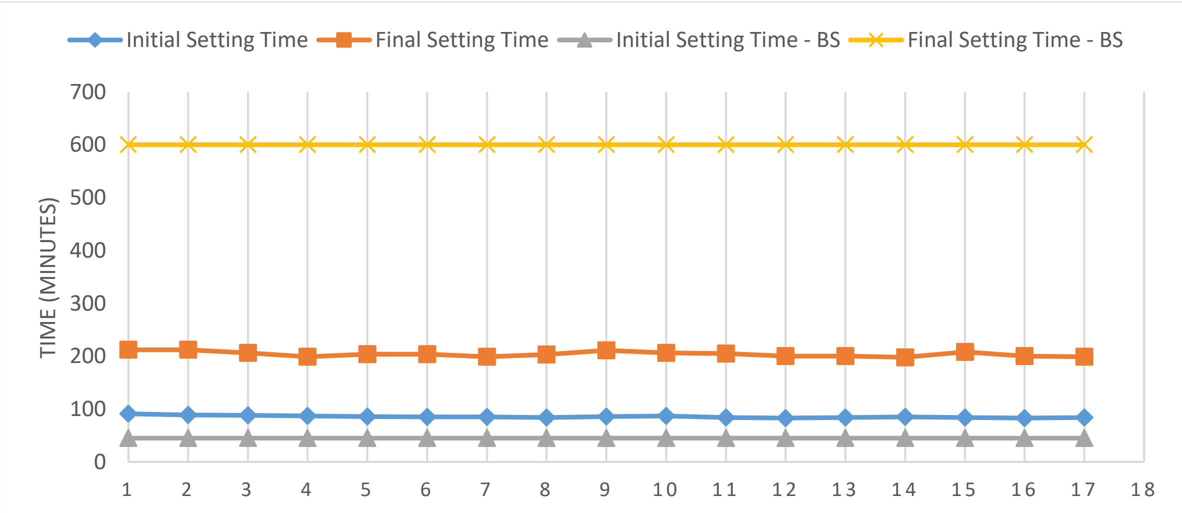

Figure 3. Setting time of Cement-CBA-BT cement Paste

Result on Soundness of Cement-CBA-BT Paste

The test was carried out as described in BS EN 196-3(2016). The soundness was measured and are presented in Figure 4. The codes specify that, for any sound paste, the expansion should be ≤10mm. All the paste prepared fell within the specified limit. This means that, the addition of CBA and BT did not add any adulteration to the cement, this means that all the mixes were sound irrespective of the percentage replacement. This result correlates the finding of Adamu *et al*, (2020), Haruna and Adamu (2020).

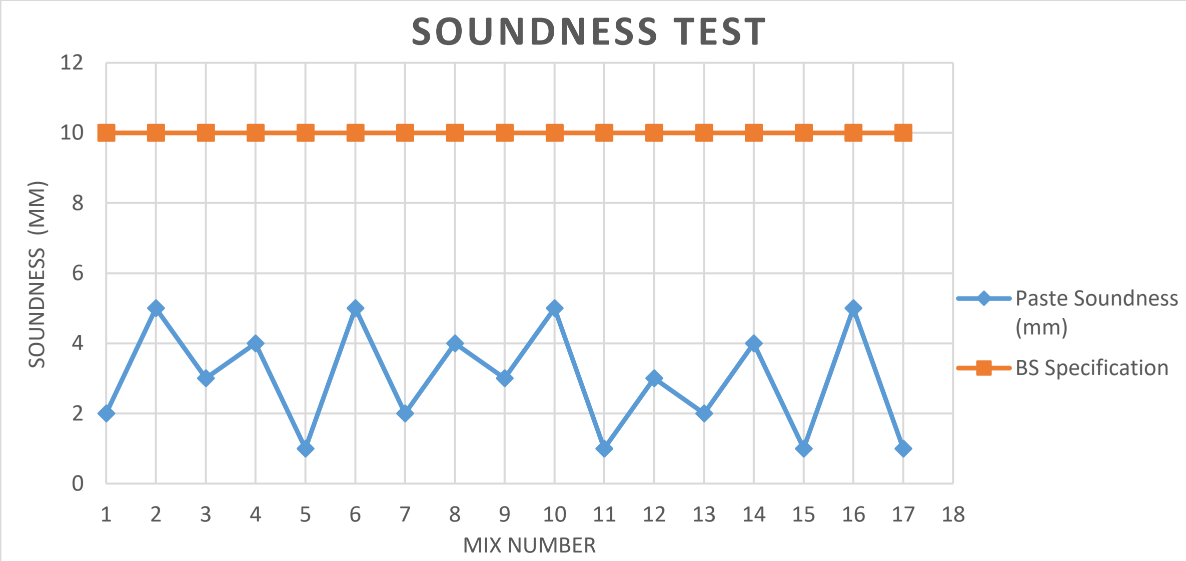

Figure 4. Soundness of Cement-CBA-BT paste

Results on Workability of Cement-CBA-BT Concrete
The workability of the Cement- CBA-BT concrete test are shown in Figure 5. According to BS EN 206-1 (2021) slump values are classified as either S1 (10 -40mm), S2 (50-90mm), S3 (100-150mm) or S4 (160-170mm). The results obtained showed that the Cement-CBA-BT concrete slump values are all within the class S3 (100-150mm). This means all the mixes were highly workable. Slump of class S3 are of high workability. Therefore, concrete with cow bone ash and bentonite has a good workability in all the mixes. Similar trend of result was obtained by Shannag (2000).

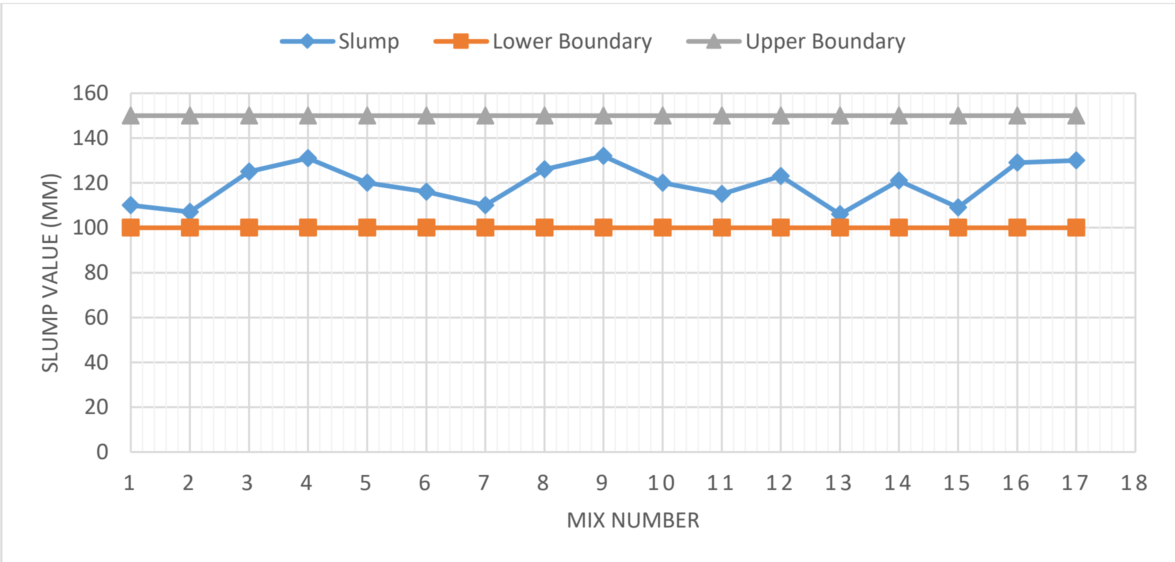

Figure 5: Slump of Cement-CBA-BT Concrete

Results on Compressive Strength of Cement-CBA-BT Concrete
The compressive strength of the cement-CBA-BT concrete is revealed at Figure 6. The compressive strength increased at 7, 14, 21, 28 and 56 days by 1, 49, 23, 14, and 8% respectively. A rapid strength development was observed in concrete from 7 – 28days across all mixes, only on 56days was an 8% gain in strength recorded. The increase and rapid gain in strength could be attributed to the new C-S-H gels formed in the matrix by the introduction of calcium oxides (CaO) and silicon oxides (SiO_2) which react with the calcium hydroxide $Ca(OH)_2$ from the Portland limestone. The maximum compressive strength was observed at 10% CBA-BT content across all curing age. Dicalcium silicate in the cement (C_2S) is responsible for later strength gain in concrete as explained by Tawfik et al (2019). Similar trend of results was obtained by Abdurra'uf et al (2017).

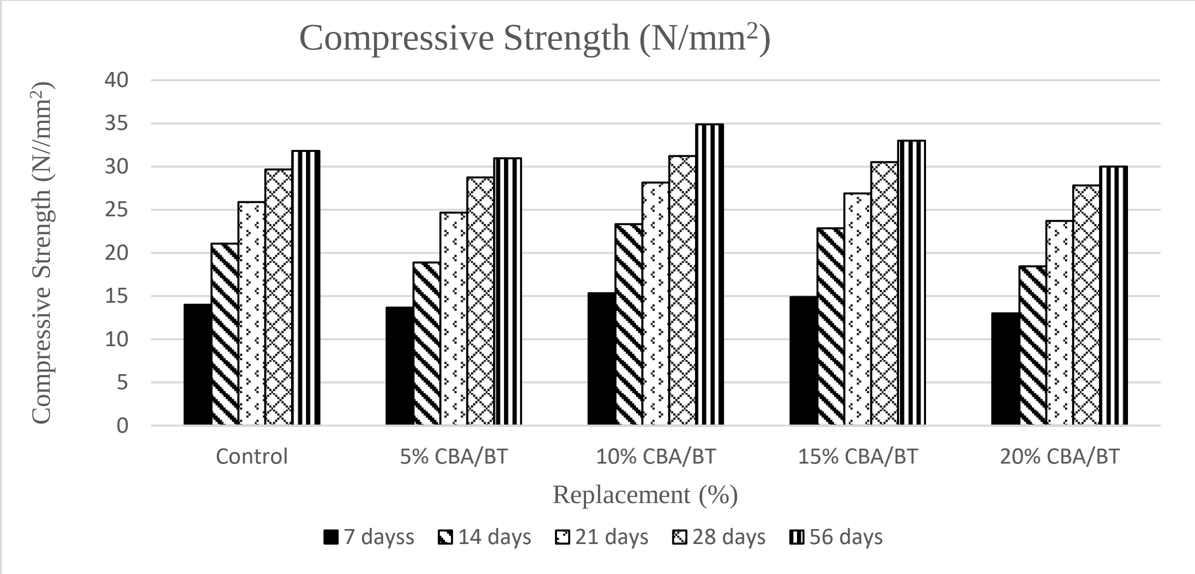

Figure 6: Compressive strength of Cement-CBA-BT Concrete

Results for Flexural Strength of CBA-BT Concrete

The flexural strength of cement- CBA-BT with different ages are shown in Figure 7. The flexural strength increased averagely by 13%, 17%, 17% 15% and 8% at 7, 14, 21, 28 and 56 days respectively. The optimum flexural strength was observed at 10/10% CBA-BT replacement across all ages. The knowledge of concrete flexural strength helps in understanding cracking development under continuous loading of beam. This results correlates with the works of Singh et al. (2016)

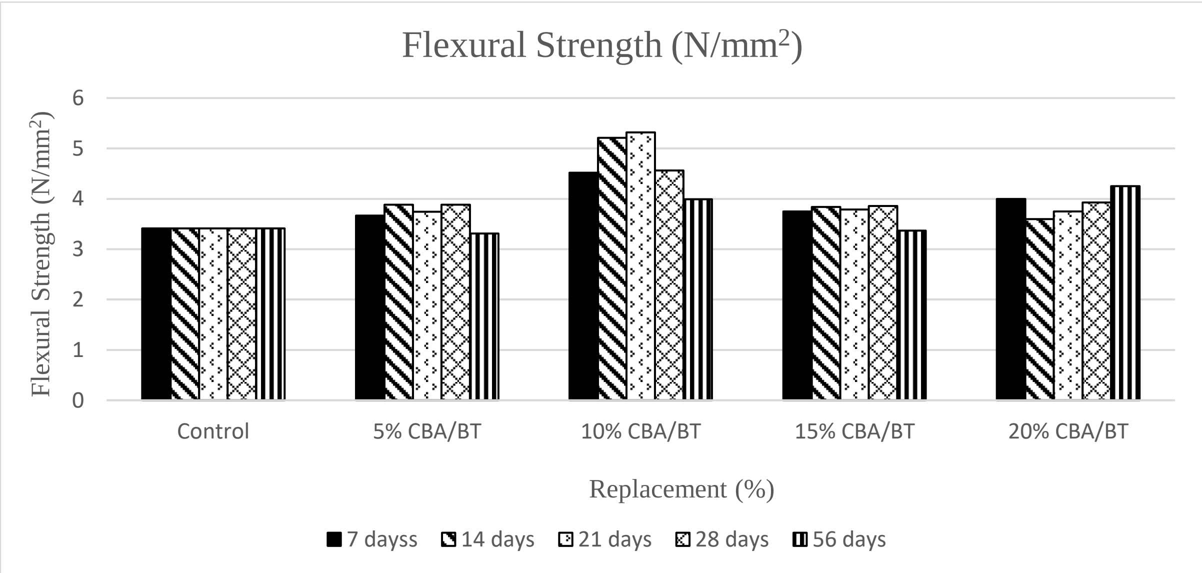

Figure 7: Flexural strength of Cement- CBA-BT Concrete

Results for Split Strength of CBA-BT Concrete

The split tensile strength of cement-CBA-BT and with different ages is presented in Figure 8**.**

The split tensile strength test was done after 7, 14, 21, 28 and 56 days of curing. It was observed at the split tensile strength marginally increased by 1% on average across all levels of replacement. The maximum increment of strength was observed at 10% CBA/BT replacement. For strength purposes 10% CBA/ CT replacement is accepted but for cost consideration 5% CBA-BT replacement is accepted due to less decrease in strength across all ages. The tensile strength of concrete helps in understanding the behavior of reinforced concrete. This results correlates with the works of Singh et al. (2016)

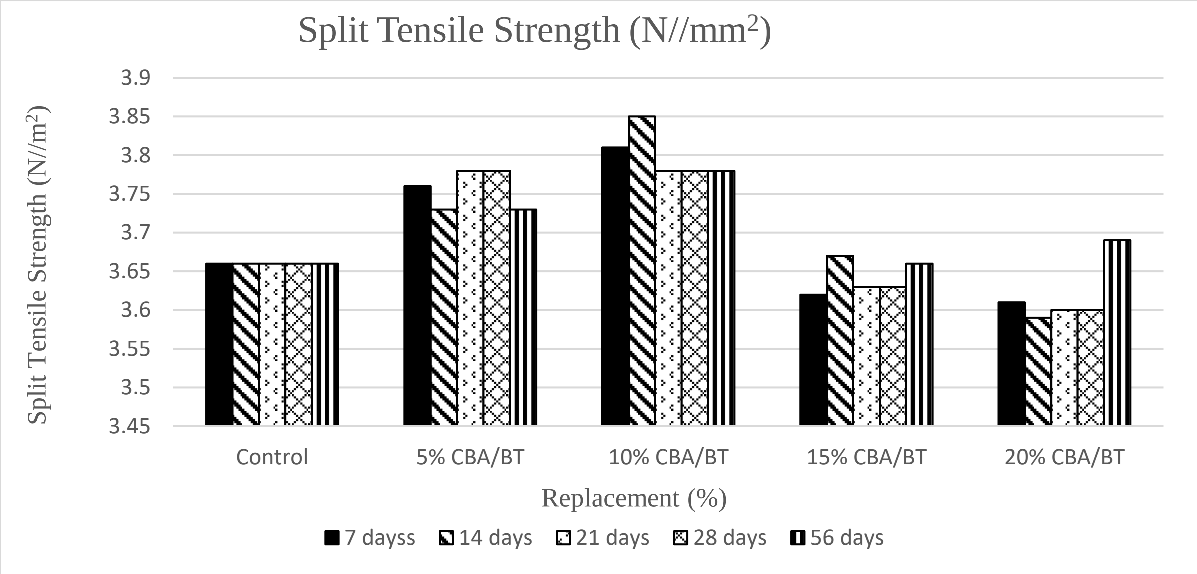

Figure 8: Split tensile strength of Cement-CBA-BT concrete

Result on Water Absorption of Cement-CBA-BT Concrete

The water absorption test result of CBA and BT is shown in Figure 9. The rate of absorption of water in concrete varies from mix to mix as the volume of voids in concrete varies. Neville (2011) stated that water absorption cannot be used as a measure of concrete quality but recommended that water absorption should be within 10% by mass of the concrete. From the results obtained it was generally observed that the water absorption in Cement-CBA-BT concrete decreases across all replacement with respect to the control. The highest water absorption was recorded at the control specimen with a weight of 2.47kg and2.49kg for the oven dry sample and saturated sample while an average 1% water absorption decrease was recorded across all mix variation. The decrease in water absorption could be attributed to the ability of the CBA and BT particles to provide a large surface are for reaction to produce C-S-H which fills the pore in the concrete material. Adamu *et al* (2020) reported that, concrete composite can have a better water penetration resistance when supplementary cementing materials that fill up voids are used

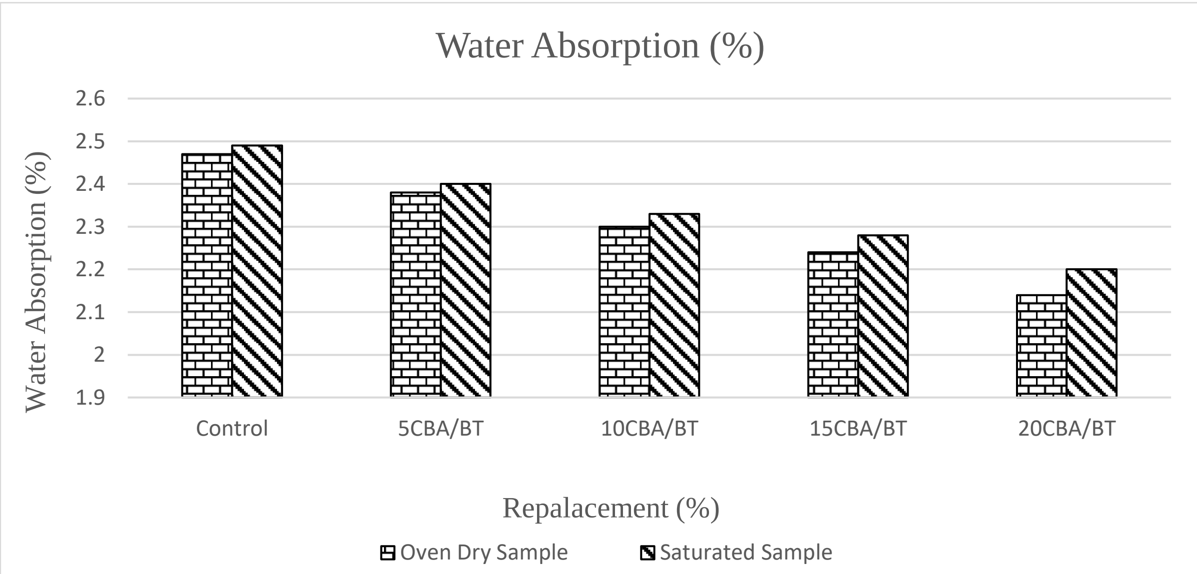

Figure 9: Water Absorption of Cement-CBA-BT Concrete

Results on Acid Resistance of Cement-CBA-BT-concrete

The compressive strength of 15% CBA-BT immersed in 5% sulfuric acid (H_2SO_4) is shown in Figure 10. It was observed that the compressive strength of CBA-BT concrete generally reduced after immersion in 5% sulfuric acid across all ages in comparison with concrete cured in water at the same age. At 7days there was a 22% decrease in strength from 30.8N/mm^2 to 25.3 N/mm$^{2.}$ a decrease of 30% in strength was recorded at 14 days from 32.6.8N/mm^2 to 25.1 N/mm^2 also 38% decrease in strength was observed at 14 days from 34.8 N/mm^2 to 25.3 N/mm^2 N/mm$^{2\ in}$ the case of 28 and 56days similar trend of reduction of 49% and 59% was observed 29.9N/mm^2 to 20.1 N/mm^2 28.7 N/mm^2 to 18.1 N/mm^2 respectively.· From results observed across mixes there was a significant reduction in strength due to mass loss which weakens the concrete matrix and threatens the structural integrity of the concrete. The observed results is in consonance with the statement of Mahmoodian and Aryai (2017) that the ingress of sulfuric acid solution through the micro pores of the concrete results in gypsum formation in the mix and as acid reaction continues it causes the concrete surface to loosen and wash away thereby causing mass loss in concrete.

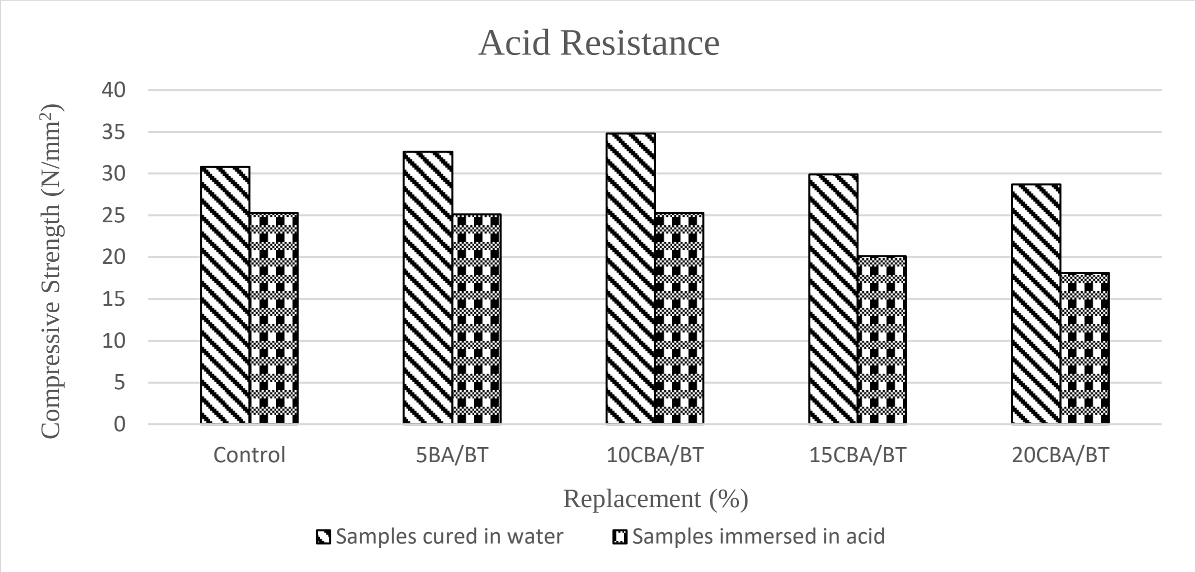

Figure 10: Acid Resistance of Cement-CBA-BT Concrete

Microstructural Analysis of Concrete Samples
Micrograph of the concrete specimen (control) at 750 magnification and 200µm scale is shown in Plate I. The microstructure analysis of the control revealed a compact rough texture concrete. The micrograph also showed pores within the concrete matrix, the pores in concrete influences the rate of water absorption and bonding matrix strength and to large extent the compressive strength of the concrete.

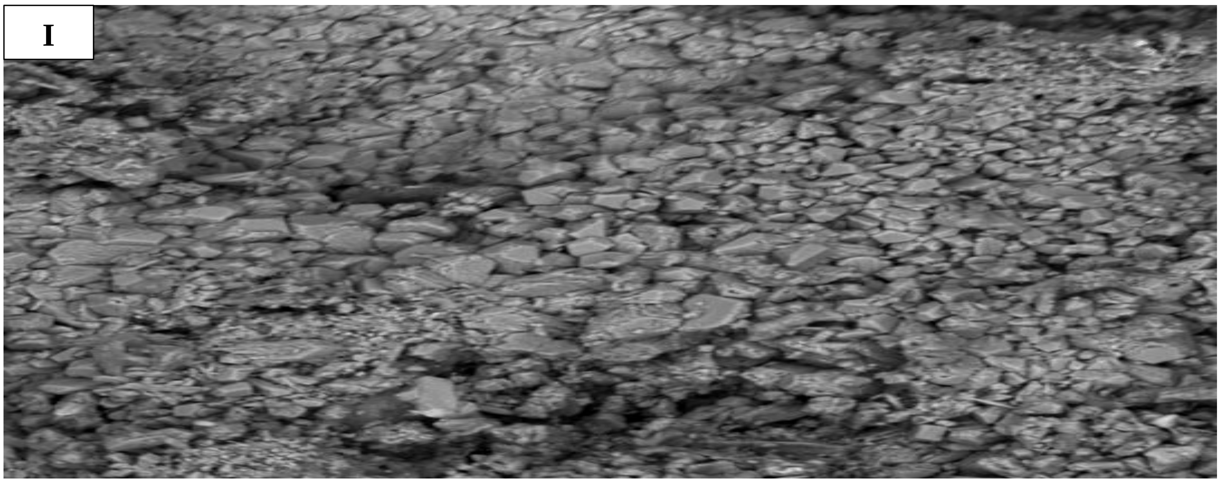

Plate I: Micrograph of concrete with Portland limestone cement (control) at 750 magnification and 200µm scale

Micrograph of the CBA-BT concrete specimen at 750 magnification and 200µm scale is presented in Plate II. The Microstructure of the CBA-BT concrete specimen reveals a smooth-like sheet coating the aggregate. This smooth-like sheet coating could be attributed to the pozzolanic reaction between the supplementary cementing materials introduced and the excess CaOH produced during the hydration of cement to produce more C-S-H bonds and C_2S which improves strength of the concrete. The microstructural analysis of the CBA-BT concrete also did not show pores within the concrete matrix this could be a contributing factor in the decrease in water absorption recorded and strength gain of concrete containing CBA-BT.

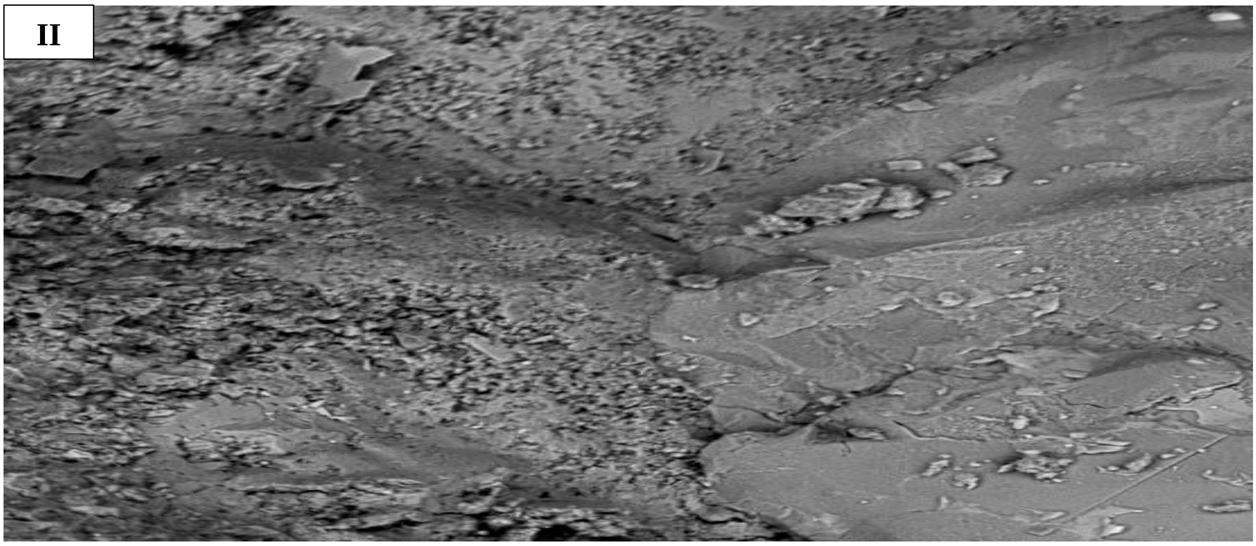

Plate II**:** Micrograph of concrete with CBA-BT at 750 magnification and 200µm scale

CONCLUSIONS

Chemical characterization of cow bone ash and bentonite showed that the materials complimented each other in the oxide composition such that it is a good replacement for cement. The workability of the mixes produced with cement blended with CBA and BT were all workable and within class S3 slump level. The maximum compressive, flexural and split tensile strength of concrete was observed at 10% CBA/BT, however other levels of replacement also showed improvements. This implies that the incorporation of cow bone ash and bentonite improves the strength properties of concrete. A reduction was recorded in the water absorption of the CBA-BT concrete specimens with respect to the control. The acid resistant test revealed a significant decrease in compressive strength of CBA-BT concrete as the days of immersion 5% H_2SO_4 in increases. The microstructure analysis of the concrete specimen containing CBA-BT showed that an improved packing and coating of aggregate when compared to the control

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