Effect of Partial Replacement of Cement with Cow Dung Ash Using Bida Natural Coarse Aggregate

Abbas, B. A.[1], Yusuf, A.[1], [1]Kolo, D. N., Aboje, A. A.[2], Mahmud, M.B.[3] & Ndaiji, A. U.[3]
[1]Department of Civil Engineering, Federal University of Technology, Minna
[2]Department of Chemical Engineering, Federal University of Technology, Minna
[3]Department of Civil Engineering, The Federal Polytechnic Bida
e-mail: bala.alhaji@futminna.edu.ng; (08065260435, 08058890435)

Abstract

The research investigates the effect of partial replacement of cement with cow dung ash (CDA) in concrete production using Bida natural coarse aggregate. Water to cement ratio and mix ratio of 0.6 and 1:2:4 was adopted respectively. The aggregates used were characterized and the cow dung was calcined at a temperature between 400-500oC. Concrete was produced using CDA as cement replacement at 0%, 5%, 10%, 15%, 20%, 25%, 30%, 35% and 40%. Slump of the freshly produced concrete was determined and the compressive strength of the hardened concrete was determined at 7, 21 and 28 days of curing. The sum of SiO2, Al2O3 and Fe2O3 in CDA exceeds the 70% minimum specified by ASTMC 618-12. The slump of the fresh concrete ranges from 0 – 40 mm while the compressive strength at 28 days curing duration ranges from 12.59N/mm2 19.29N/mm2 and density was 2323.95kg/m^3– 2554.59kg/m^3 respectively. The test results revealed that the compressive strength decrease with increase in CDA content and increase with curing age. The strength results indicate that there was no much significant difference between the control specimen with 0% CDA and that containing 5% CDA. This implies that concrete made using CDA as partial replacement for cement can be used for structural applications such as in the construction of reinforced concrete slabs, beams, columns and foundations. The study concluded that CDA has pozzolanic properties and can be used to replace up to 10% cement in concrete produced using Bida natural coarse aggregate.

Keywords: *Concrete, Cement, Cow dung Ash, Compressive Strength, Workability*.

Introduction

Concrete is one of the most widely used construction material worldwide and there is an increase in the production of concrete to meet the ever-increasing demand for housing and other infrastructure. Concrete is a composite material consisting of aggregate (gravel and sand), cement, and water. Concrete is one of the construction materials which determine the strength, durability and structural performance of most construction work. Concrete is a man-made composite, a major constituent of which is natural aggregate such as gravel and sand or crushed rock (Alhaji, 2020. Alternatively, artificial aggregate such blast furnace slag, expanded clay, broken bricks and steel shots may be used where appropriate. The hardened concrete may be considered as an artificial stone in which the void of larger particles (coarse aggregate) is filled by the smaller particle (fine aggregate) and void of fine aggregate are filled with cement. The cementitious material and water form a cement paste which in addition to the filling of the void of fine aggregate coats the surface of fine and coarse aggregate together to form a compact mass. Concrete occurs in both fresh and hardened state. It fresh state must undergo proper workability, consistence, setting, handling, placing, transportation and compaction for it to be satisfactory. This fresh concrete solidified and hardened after placement and develops strength over time (Olaniyan, 2001). As a construction material, concrete can be cast in almost any shape desired, and once hardened, can become a structural (load bearing) element.

Cement, which is the main binder in the production of concrete, mortar, sandcrete blocks and other cement-based products, is very expensive particularly in developing countries (Awoyinfa, 2013). The activities of cement producing companies have depleted the natural environment and huge amount of poisonous gases such as Carbon dioxide CO_2, NO2, are released into the atmosphere causing environmental pollution. These gases are also responsible for depletion of the ozone layer which is responsible for global warming (Shalini, *et al.*, 2006).

Portland cement is the most common type of cement in general use around the world, used as a basic ingredient of concrete and mortar. It was developed from other types of hydraulic-lime in England in the mid-19th century and usually originates from limestone. It is a fine powder produced by heating materials in a kiln to form what is called clinker, grinding the clinker, and adding small amounts of other materials. Several types of Portland cement are available with the most common being called ordinary Portland cement (OPC) which is grey in color, but a white Portland cement is also available, Portland cement is caustic so it can cause chemical burns, the powder can cause irritation or with severe exposure lung cancer and can contain some hazardous components such as crystalline silica and hexavalent chromium. Environmental concerns are the high energy consumption required to mine, manufacture, and transport the cement and the related air pollution including the release of greenhouse gases, dioxin, NO2, SO2, and particulates (Yong & Ouhadi, 2007).

The low cost and widespread availability of the limestone, shales, and other naturally occurring materials used in Portland cement make it one of the lowest-cost materials widely used over the last century throughout the world. Concrete produced from Portland cement is one of the most versatile construction materials available in the world.

Cow dung is basically the rejects of herbivorous matter which is acted upon by symbiotic bacteria residing within the animal's rumen. Cow/Cattle are mostly found in every part of Nigeria while they are mostly breed in the northern states of the nation such as Niger State, Plateau state, Nassarawa state, Kaduna state and Jigawa state. (Olawale and Suley, 2012).

Cow dung comprises of organic matter including fibrous material that passed through the cow's digestive system, among other liquid digester that has been left after the fermentation, absorption and filtration, then acidified, then absorbed again. Exact chemical composition is of mostly carbon, nitrogen, hydrogen, oxygen, phosphorus, etc. with salts, cells sloughed off as the digester went through the digestive tract, some urea, mucus, as well as cellulose, lignin and hemicelluloses (Pavan *et al.,* 2012).

A full-grown well-fed cow produces between 10-15kg of cow dung per day which contains about 28% water in its fresh state and 34% ash when calcined (Olusegun and Sam, 2012). The world cattle population is estimated at 1.4 billion (Food and Agricultural Organization, 2010). Nigeria has an estimated cow population of 16 million and is expected to produce an estimated 264,000tons of cow dung per day (Salisu, 2007). In many parts of the world, cow dung is predominantly used as green manure for farming. It is also used with adobe in brick production, insect repellant and more recently used to produce biogas (Marek, 2012) for electricity and heat generation. It can be noted that despite its application in the aforementioned areas, its production outweighs the usage (Olusegun and Sam, 2012)

Cow dung was habitually used in concrete and recent publications suggest that dung may improve workability and durability or may act as an additional binder. Knowledge has also been lost as to whether fresh, old, or weathered dung was used. Since there is no historic reference to the dung being old or weathered, it is conceivable that this is a recent invention resulting from modern attitudes toward odour and hygiene. In any case, dried and fresh dung differ mainly in the water content and so are likely to affect only the amount of water, if any, added during mixing of the concrete. This illustrates the literature of the active cow dung component in concrete.

Materials nd Methods

Materials

The material used includes Ordinary Portland Cement (OPC), Cow Dung Ash (CDA), clean river Sand, Bida Natural Coarse Aggregate and water. (The material preparation took place at the Civil Engineering Department Laboratory of the Federal University of Technology, Minna.

River sand: The natural sharp sand used were extracted from Gidan Mangoro, Minna, Niger state. The sample collected were air-dried inside the civil engineering laboratory to enhance better concrete production. the sharp sand was clean, well graded in accordance with the set requirements of ASTMC 114, standard specification of aggregate for conventional concrete.

Cement: The Cement used for this research work is Ordinary Portland Cement obtained from an open market in Gidan Kwano Minna.

Cow dung: was obtained from the University farm in the Campus. The cow dung was exposed to sunlight to dry in order to have dung cakes which was subjected to burning within the university premises in Gidan Kwano campus after it was dried to have the cow dung ash. The resultant ash was grinded into finer particle using mortar and pestle and was sieved using sieve 75mm size.

Coarse aggregate: Bida Natural Coarse aggregate (Plate I) were used and obtained from Bida town Niger State in Nigeria. The aggregate was passed through a set of sieves to know their actual sizes. The aggregates that pass-through BS sieve 20mm and retained on BS sieve 14mm to 5mm were used for the research work.

Plate I: Bida natural stone

Methods

The Methodology include Laboratory experiment and this consist of preparing and testing of fresh and hardened concrete specimen of normal concrete and CDA concrete, All the samples were tested based on laboratory preliminary test with Sieve Analysis of fine aggregate and coarse aggregate, Specific gravity of fine aggregate and coarse aggregate, Slump test and Compressive strength test carried out according to standard specification.

A total of 81 concrete cubes of 150mm x 150mm x 150mm dimension were cast. The percentages of substituting the cement with CDA varied at 0%, 5%, 10%, 15%, 20%, 25%, 30%, 35% and 40% of Cement and values of their respective compressive strength were taken at 7days, 21days and 28days of hydration periods.

The compressive strength of the Sample was determined after the specific curing periods and demoulding according to Standard Specification.

Production of Concrete specimen: Moulds of (150×150×150) mm^3 were used. They were lubricated with engine oil in order to reduce friction and to enhance removal of cubes from the moulds. They were then filled with concrete in three layers and each layer was tamped 25 times. The moulds containing the cubes were left for 24 hours under a room temperature for the cubes to set before removing the mould. The cubes were removed after 24 hours and were taken to curing tank (BS EN 12390, 2002).

Curing of Concrete Cubes: The method use for curing in this work is the total immersion of the cubes in water for specific age of 7, 21 and 28 days from the day of casting (BS EN 12390-2:2000)

Compressive Strength Test: The concrete cubes were crushed at 7, 21, and 28 days in order to determine the compressive strength of the cubes. The compressive strength in N/mm^2 is determined by dividing the maximum of failure load of the specimen during the test by the cross-sectional area of the specimen, BS EN 12390 (2002). Compressive strength is evaluated using Equation 3.1

$$Copressive\ Strength = \frac{Crushing\ Load}{Cross\ sectional\ Area} \quad (1$$

Results And Discussion

Results of physical properties

Table 1: Physical Properties of the Aggregates

Parameter	Sand	Bida Gravel	Cow dung	Cement
Specific gravity	2.56	2.61	2.53	3.15
Natural moisture content	4.94	2.02	-	-
Compacted Bulk density (kg/m^3)	1615.10	1786.46	-	-
Uncompacted bulk density (kg/m^3)	1460.30	1640.16	-	-
Void ratio	0.90	0.92	-	-

Results of sieve analysis

Table 2: Sieve analysis of Fine aggregate (Sand).

Sieve size (mm)	Weight of sieve (g)	Weight of sieve + sample retained (g)	Weight of sample retained (g)	Percentage of sample retained (%)	Cumulative percentage retained (%)	Percentage of sample passing (%)
5.000	476.65	480.2	3.55	1.11	1.11	98.89
3.350	468.63	481.9	13.27	4.14	5.25	94.75
2.360	427.72	450.5	22.78	7.10	12.35	87.65
2.000	418.46	430.3	11.84	3.69	16.04	83.96
1.180	386.46	433.0	46.54	14.51	30.55	69.45
0.850	354.45	385.2	30.75	9.58	40.13	59.87
0.600	468.38	508.6	40.22	12.54	52.67	47.33
0.425	435.51	461.7	26.19	8.16	60.83	39.17
0.300	312.55	335.1	22.25	7.03	67.86	32.14
0.150	421.11	464.2	43.09	13.43	81.29	18.71
0.075	372.75	397.9	25.15	7.84	89.13	10.87
Pan	270.89	305.8	34.91	10.88	100	0

Table 3: Sieve analysis of Coarse Aggregate (Bida Gravel)

Sieve size (mm)	**Weight of sieve (g)**	**Weight of sieve + sample retained (g)**	**Weight of sample retained (g)**	**Percentage of sample retained (%)**	**Cumulative percentage retained (%)**	**Percentage of sample retained (%)**
28	1.61	1.61	0.00	0.00	0.00	100.00
20	1.48	1.51	0.03	2.97	2.97	97.03
14	1.42	2.07	0.68	64.36	67.33	32.67
10	1.37	1.61	0.24	23.76	91.09	8.91
5	1.50	1.59	0.09	8.91	100	0
Pan	0.83	0.83	0.00	0	100	0

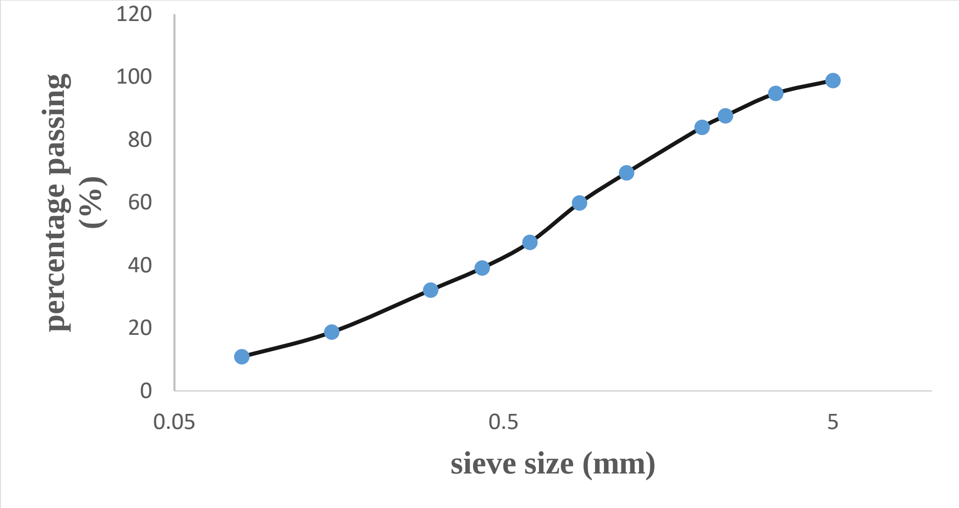

Figure 1: Particle Size Distribution of Fine Aggregate (Sand)

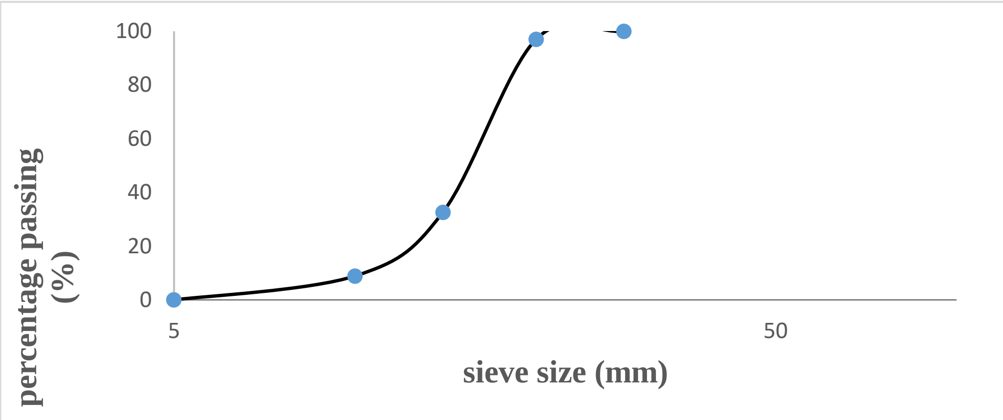

Figure 2: Particle Size Distribution of Coarse Aggregate (Bida Gravel)

Chemical Composition of CDA

Table 4: Chemical Composition of CDA

Element	Composition (%)	ASTM C618-12 Requirement
Na_2O	0.926	
MgO	3.659	
Al_2O_3	9.785	
SiO_2	64.65	$SiO_2+Al_2O_3+Fe_2O_3 \geq 70\%$
P_2O_5	3.449	
SO_3	1.990	
Cl	0.791	
K_2O	2.626	
CaO	7.416	
TiO_2	1.068	
Cr_2O_3	0.002	
Mn_2O_3	0.183	
Fe_2O_3	3.365	
ZnO	0.021	
SrO	0.060	

Discussion of result of physical properties of aggregate

The result of specific gravity, bulk density (compacted and uncompact) and moisture content are presented in Table 1. The specific gravity of Bida natural stone, Cow dung ash, fine aggregate are 2.61, 2.53 and 2.56 respectively. This value obtained fall within the limit for natural aggregate 1.3-3.0 and 2.6-2.7 respectively. It implies that aggregate can be conveniently use for construction work (concrete) without much need for mix proportioning adjustment (Naville, 1995). The specific gravity of CDA is 2.53, which is also close that of Ordinary Portland cement. This in an indication that CDA can therefore be suitable for substitution of cement for concrete production.

The bulk density: result is 1640.16kg/m³ (uncompacted) and 1786.46kg/m³ (compacted) for Bida natural stones, which classified Bida natural stones as normal weight aggregate, Table 1. Also the compacted and uncompacted bulk density of sand are 1615.10kg/m^3 and 1460.30kg/m^3 which agree with the value of 1625kg/m^3 and 1542.00kg/m^3 report by Alhaji (2020)

Sieve analysis: The result obtained for sieve analysis of both sharp sand and gravel was recorded as shown in Tables 2.0 and 3.0. However, from Figure 1.0 the curve shows as S-curve showing that the sharp sand is well graded and therefore, adequate for producing a workable concrete. Also, Figure 2.0 shows a smooth grading curve which is an indication that the Bida aggregate is adequate for production of workable concrete.

Chemical analysis of CCA: Table 4.0 shows the chemical composition of cow dung ash. The total percentage composition of iron oxide (Fe_2O_3=3.365), Silicon dioxide (SiO_2=64.65) and Aluminum oxide (Al_2O_3=9.785) was found to be 77.8%. The value is within the required value of 70% minimum for Pozzolanas as specified by ASTM C618 (2005). This value is little more than the value obtained by Alhaji (2006) for Corn cob ash (CCA) (72.4%) which implies that Cow dung ash (CDA) is more pozzolanic.

Results of Concrete properties

Slump test

Table 5: Result of slump test of a fresh concrete

% Replacement of Cement with CDA	Concrete Mix	Water/Cement Ratio	Slump (mm)	Slump type
0	1:2:4	0.60	40	True
5	1:2:4	0.60	35	True
10	1:2:4	0.60	30	True
15	1:2:4	0.60	25	True
20	1:2:4	0.60	15	True
25	1:2:4	0.60	10	True
30	1:2:4	0.60	5	True
35	1:2:4	0.60	0	Zero
40	1:2:4	0.60	0	Zero

Compressive strength of concrete

Table 6: Summary of Average 7-, 21- and 28-Days Compressive strength of Concrete with varied percentage Replacement of Cement with Cow dung ash

S/No	% Replacement	Average Compressive strength (N/mm^2) 7days	Average Compressive strength (N/mm^2) 21days	Average Compressive strength (N/mm^2) 28days
1	0	12.81	18.92	19.29
2	5	12.42	18.18	18.43
3	10	12.01	17.18	17.94
4	15	9.81	15.79	16.72
5	20	8.59	15.42	15.80
6	25	6.63	14.86	15.32
7	30	6.59	14.15	14.93
8	35	6.52	13.13	14.83
9	40	6.31	12.49	12.59

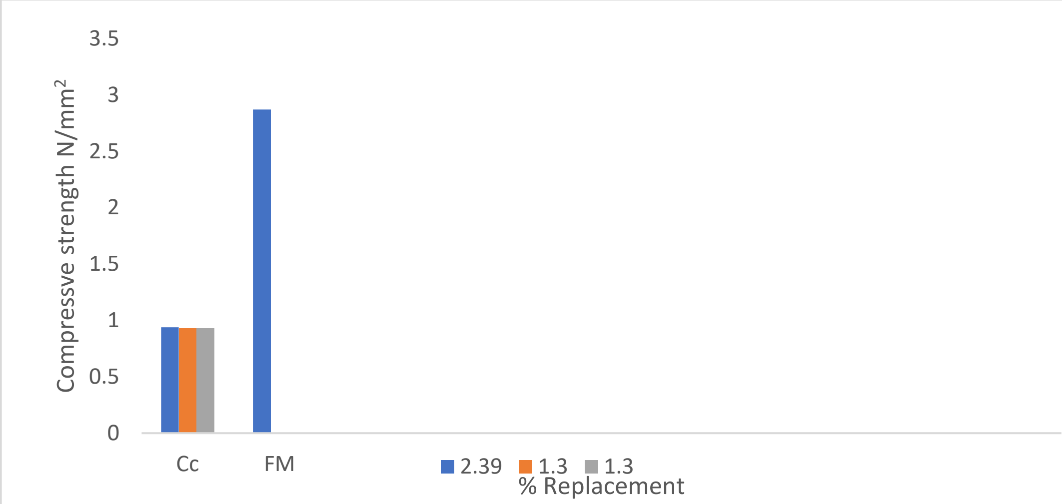

Figure 3: Compressive strength against % Replacement

Dry density

Table 7: Summary of Average 7-, 21- and 28-days Dry Density of Concrete with varied percentage Replacement of Cement with Cow dung ash

S/No	% Replacement	Average Dry Density (kg/m^3) 7days	Average Dry Density (kg/m^3)21days	Average Dry Density (kg/m^3)28days
1	0	2450.37	2579.03	2596.54
2	5	2423.70	25700.24	2590.62
3	10	2413.95	2529.38	2488.89
4	15	2381.60	2510.75	2439.51
5	20	2360.12	2403.95	2379.13
6	25	2345.43	2396.05	2367.04
7	30	2327.72	2359.63	2327.35
8	35	2300.12	2341.07	2267.04
9	40	2283.95	2303.46	2127.35

Discussion of result of slump test, Compressive strength and Dry density of a concrete

Slump test: The result of slump is presented in Tables 5. The result shows that workability of concrete reduced with increasing CDA content. Hence reduction in workability observed in this research work is a true reflection of the physical properties of material constituent explained above. Thus, mix with 0% and 30% replacement gave a true slump and these mix with 35% and 40% provided a zero slump, meaning that the effect of admixtures toward workability was inversely proportional to the CDA content.

Compressive strength: The result of compressive strength and dry density are as shown in Table 6, the strength increases as the curing age increases. This is primarily due to the fact that concrete hardening is caused by chemical reaction between cement and water which continues for a long period of time and consequently, concrete get stronger with age (Gambir, 2004). The range of value of compressive strength for normal strength concrete is $20N/mm^2$-$40N/mm^2$. It was also observed that the strength decreases along with the increment of the Cow dung ash, this behaviour is also a true reflection of lower binding ability of Cow dung as compare with Ordinary Portland cement, thus the substitution of which leads to a reduction in the strength of the concrete. However, the result of percentage replacement at 5% with compressive strength of $18.43N/mm^2$ is very closer to the lower limit of normal strength concrete which is the optimum replacement and can be used for structural purpose such as reinforced concrete slab, beam, column and foundation with minimum adjustment in the factor of safety.

Dry density: The result of dry density is as shown in Table 7. Dry density of the concrete is within the range of 2596.54- 2127.35kg/m^3 for mix 0%-40% and respectively. However, based on the research reported by Agede and Manasseh (2009) who stated that those concrete with dry density between 300 – 800kg/m^3 can be classified as low-density concrete, those between 960-1300kg/m^3 are moderate strength concrete and the once having density in the range of 1350-1900kg/m^3 are structural light weight concrete. while Normal weight concrete are these with density of 2200-2600kg/m^3 (Agede and Manasseh, 2009). Hence the concrete with mixes 0% to 40% with dry density as stated above can be classified as Normal weight concrete

Conclusion

Based on the results of the research, the following conclusion are made;

1) The chemical composition of cow dung ash as shown that it can can be classified as a class N pozzolana according to ASTM C618-2012 specification.

2) The Strength Activity Index of CDA is 77.8% which exceeds the 70% minimum set by ASTM C618-2012 and thus CDA can be used as a Supplementary Cementitious Material for mortar and Concrete Production

3) The use of CDA as cement replacement in concrete has the potential to reduce the risk of late expansion

4) Compressive strength decreases as the CDA content increases and increases as the curing period is prolonged.

5) With strength as a criterion, CDA of no more than 5% can be used to produce good and quality mortar and concrete.

6) Cow dung ash addition of no more than 5% resulted in significant long-term increase in compressive Strength.

Recommendations

From conclusion drawn in this research work, it is therefore recommended that;

1. Cow dung ash can be used as a partial replacement of cement (5%) especially in places where is in abundance.

2. Concrete should be properly cured to the achieve properties of design strength, durability and long-lasting serviceability.

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Performance Evaluation of Cement-Stabilized Soft Clay Admixed with Coal Bottom Ash

*Zubbair, M. A.[1], Adejumo, T. E.[1], Amadi, A. A.[1] & Shehu, M.[1]
[1]Civil Engineering Department, Federal University of Technology, Minna Niger State, Nigeria
*Corresponding author email: mukhtarayomidezubbair@gmail.com (+2348034379758)

Abstract:

This research investigated the effect of adding cement and coal bottom ash at varying percentage on the consistency limits, compaction characteristics, unconfined compressive strength and CBR of the soil sample. Soil sample was collected from a borrow pit at depths of 1.5m and 2m. Index properties tests were conducted on the soft clay sample and classified under A-7-6, CL according to America Association of State Highways and Transportation Officer (AASHTO) and Unified Soil Classification System (UCSC) respectively. Result of the analysis revealed that the Liquid Limit increased with increasing cement and coal bottom ash content and Plasticity Index reduced with increasing percentage of cement and CBA. Plastic Limit increased from 25.32% for natural soil to 40.66% at 3:6% cement and CBA content and then returned to 0% at 6:9%, 9:12% and 12:15%. However, it was observed that Increasing cement and coal bottom ash content from 0 – 12:15% in the stabilized soil mixtures indicates a progressive increment in the MDD values for BSL, WAS and BSH. BSH gave the highest values of MDD which ranges between 1.77 – 1.83 g/cm³ and corresponding OMC values between 16.00 – 21.50% for mixtures tested. However, for BSL and BSH compaction cement and coal bottom ash content at 3:6% gives the highest MDD at the respective energy level. Addition of cement and coal bottom ash to the natural soil shows improvement in the UCS values of the stabilized specimen. BSH gave the highest value of 5871.92kN/m² for UCS at 28 days of curing.

Keywords: California bearing ratio, Coal bottom ash, soft clay, Stabilization, Unconfined compressive strength.

1.0 Introduction

Soft clay soils are recent alluvial deposits presumably formed through the most recent 10,000 years described by their featureless and flat ground surface. (Hussein *et al*., 2015) identified such clays by their low undrained shear strength (Cu<40 kPa) and high compressibility (Cc 0.19 to 0.44). These soils are found at high natural moisture content (typically ranging from 40-60%) with plasticity index ranging from 45-65% (Broms, 2017). Soils with such characteristics create serious problems to geotechnical engineering associated with stability and settlements problems (Abbawi, 2011). A soft sub grade in construction of roadways is one of the most frequent problems for highway construction in many parts of the world (Broms, 2017)

Soil stabilization, soil re-engineering or ground improvement is the process of altering or improving the one or more properties of weak or problematic soil in order to improve its performance under engineering load (Afrin, 2017; Zaliha *et al*., 2013). However, the choice of soil stabilization agents and soil stabilization technique is largely dependent on the index properties of the soil (EuroSoilStab, 2002). Lime, fly ash, Portland cement, blast furnace slags, rice husk, banana leave ash, bitumen or tar, polymers, fiber reinforcement, solid waste, organic matter, etc. have recorded some success to have been used as soil stabilizer over the year by researchers and engineers (Zumrawi and Hamza, 2012; Makusa, 2012; Abdullah *et al*., 2015; Ayyappan *et al*.2017; Afrin, 2017). Little has been done on the use of coal bottom ash as a soil stabilizer, although coal bottom ash has found applications in concrete production as partial replacement of sand and cement and as a pozzolan.

Coal bottom ash, a byproduct of coal combustion and a waste product of the locomotive system of train in rail transportation has found application as in concrete production as partial replacement of sand (Singha and Siddiqueb, 2013) as partial replacement of Portland cement (Kurama and Kaya, 2008) and as pozzolan (Jaturapitakkul and Cheerarot, 2003). This study intends to investigate the use of coal bottom ash in soil stabilization. The use of coal bottom ash will help create a synergy between Nigerian rail transportation, which is undergoing resuscitation, and its failing road transportation.

2.0 Materials and Methods

2.1 Materials

2.1.1 Soft Clay

The soft clay sample was collected from a borrow pit around Lapai-Gwari village, Chanchaga Local Government Area, Niger State. It was collected by method of disturbed sampling in conformity with BS 1377 (1992) at depths of 1.5 m to 2.0 m below the ground surface to avoid organic matter. The sample was then wrapped in polythene bags to avoid loss of moisture and transported to the Civil Engineering Laboratory, Federal University of Technology, Minna.

2.1.2 Coal bottom ash

The coal bottom ash used for the purpose of this study was obtained from a supplier in Kogi State.

2.1.3 Ordinary Portland Cement (OPC)

Dangote cement brand of grade 32.5 was used as the main binder because it is in conformity with BS EN 197-1:2000.

2.1.4 Water

The water used for this study is clean and portable, in accordance with BS EN 1008:2002.

2.2 Soil Sample Preparation

The physical properties of Coal bottom and Cement used were different, adding the additives is to identify the effect of constituents, changes that occur in the soil properties texture and water content of the sample. It was dried in the open air, and grinded into fine particles, and was made to pass through the B.S sieves.

2.3 Methods

2.3.1 Determination of Engineering Properties of collected sample

To determine the effect of stabilizers on soft clay sample, tests were carried out on the soft clay in accordance to BS 1377. Sieve analysis, Compaction, Atterberg limit test, California bearing ratio (unsoaked) and Unconfined compressive strength test was carried out.

2.3.2 Laboratory Experiments on Soft Clay

The laboratory experiments were conducted in accordance with B.S 1377 (1990). The engineering properties of the soil were determined using percentage of admixtures ranging from 3:6%; 6:9%; 9:12% and 12:15% respectively.

3.0 Results and Discussion

3.1 Index Properties of Soft Clay

The results of the preliminary tests conducted for identification and the determination of the properties of the natural soil are presented in Table 1 while the particle size distribution curve is shown in Figure 1. The soil is classified by AASHTO as A-7-6 and CL in the unified soil classification system (USCS) is reddish in colour and its geotechnical properties falls below the standard recommended for most civil engineering construction works especially highway construction (Osinubi and Medubi, 1997).

Table 1: Index Properties of Natural Soft Clay

Property	Value
% Passing BS sieve No. 200	82.20%
Specific Gravity	2.46

Liquid Limit	46%
Plastic Limit	25.32%
Plasticity Index	20.68%
AASHTO Classification	A-7-6
USCS classification	CL
Colour	Reddish

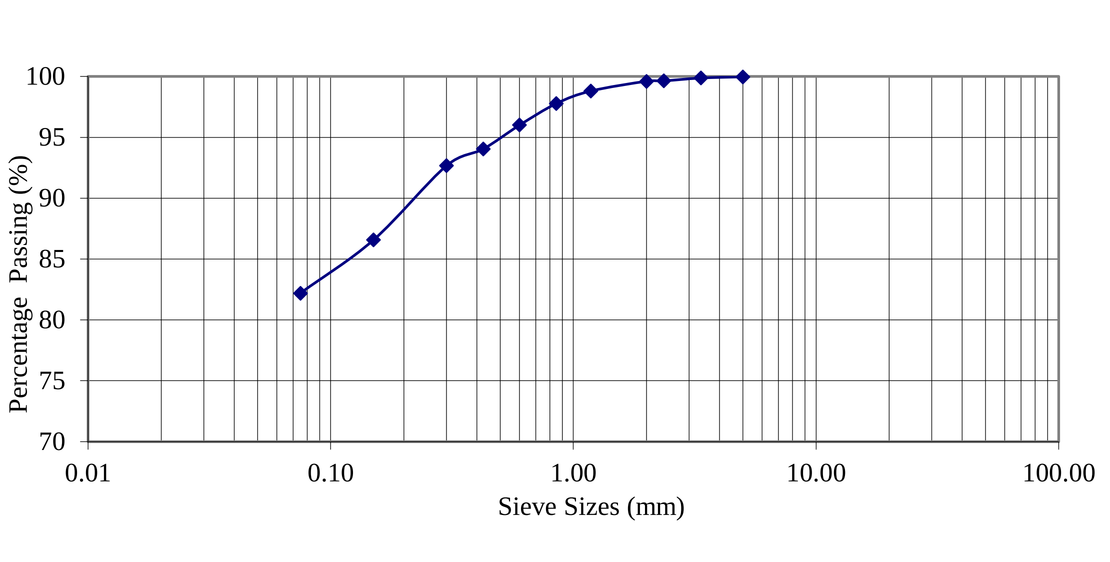

Figure 1: Particle size distribution curve of the Natural soft clay

3.2 Consistency Limits

Figure 2 shows the result of consistency limits of the natural soil and stabilized soil specimens using cement and coal bottom ash at 3:6%; 6:9%; 9:12% and 12:15%. Liquid limit of the natural soil increased from 46% to 82% upon adding 12:15% cement/coal bottom ash to the natural soil specimen. The Plastic Limit increased from 25.32% for the natural soil to 40.66% at 3:6% cement/coal bottom ash content before dropping to 0% at 6:9%, 9:12% and 12:15%. The Plasticity Index reduced significantly from 25.32% to 0% in the same sequence of cement and coal bottom ash treatment. Cement and coal bottom ash increased the compressibility and shrinkage/swelling potential of the soil due to the progressive increase in its liquid limit as well as shear strength as plastic index decreased with increasing cement/coal bottom ash content. The improved natural soil sample however, failed to meet Liquid Limit requirements for subgrade materials which is specified as; LL $\leq$ 35 but the Plastic Limit specification was met at PI $\leq$ 13% according to Federal Ministry of Works and Housing (1997).

According to Monther *et.al.* (1997), the Liquid Limit for clay decreased from 125 to 100% when coal bottom ash was used to stabilize it at varying percentages. Then, failure of mixtures to meet the required threshold values for liquid limit parameters suggests that lower cement content may be needed to achieve the specification requirements.

3.3 Strength Tests

3.3.1 Compaction

Figure 3 show how the Maximum Dry Density changes with the addition of cement and coal bottom ash for BSL, WAS and BSH Energy levels compaction. The MDD ranged from 1.56g/cm³ to 1.62g/cm³ for BSL, from 1.67g/cm³ to 1.77g/cm³ for WAS and from 1.77 g/cm³ to 1.83g/cm³ for BSH compaction as the cement and coal bottom ash content increased from 0 – 12:15%. Generally, the density of the soil increases with increasing cement/coal bottom ash content. British Standard Heavy which has the highest energy level of the three compacting efforts gave highest set of results, having MDD values ranging from 1.77 – 1.83g/cm³. The increase in MDD values suggest that increase in cement and coal bottom ash content has positive influence on the strength and density characteristics of the natural soil sample.

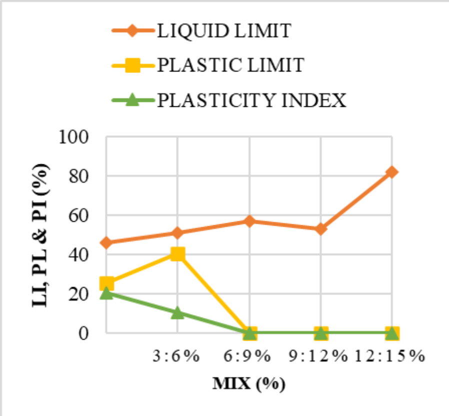

Figure 2: Variation of Atterberg limits value with %Cement and %Coal Bottom Ash

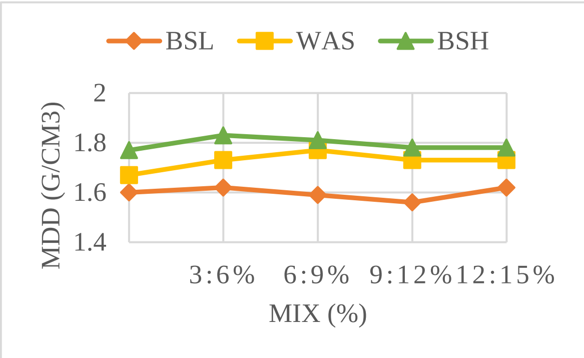

Figure 3: MDD with %Cement and %Coal Bottom Ash

Figure 4 shows how the optimum moisture content changes with the addition of cement and coal bottom ash for BSL, WAS and BSH compaction. In general, the OMC ranged from 20.30 – 25.50% for BSL, 17.40 – 23.20% for WAS and 16.00 – 21.50% for BSH as the cement/coal bottom ash content increased from 0 – 12:15%. The moisture range for the British Standard Heavy compaction was the lowest. In general, at higher compacting effort, higher MDD is attained at reduced OMC due to increase in the energy level and the rapid expulsion of voids in soil samples. The moisture contents at this energy level for the improved soil meet the requirement for subgrade material which is specified at w (%) < 18% according to Federal Ministry of Works and Housing (1997).

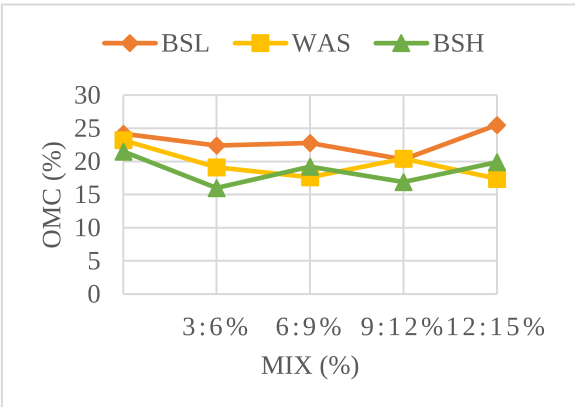

Figure 4: OMC with %Cement and %Coal Bottom Ash

3.3.2 California Bearing Ratio (CBR)

CBR is used to evaluate the strength property of subgrade soil in road construction. Unsoaked conditions were tested for the three compaction energy levels adopted in this research with cement and coal bottom ash content ranging from 0 – 12:15%. Figure 5 present the unsoaked CBR result which shows progressive increment in CBR value of the stabilized soil. Therefore, the results for WAS and BSH compaction satisfy the minimum requirement of 30% for unsoaked CBR when used as subgrade in flexible pavement construction according to Federal Ministry of Works and Housing (1997). The CBR results obtained shows that cement and coal bottom ash has significantly increased the strength properties of the natural soil when stabilized with cement/coal bottom ash for unsoaked CBR. Therefore, the load bearing capacity of the natural soil improves with the stabilization mix. The progressive increase in the California Bearing Ratio (CBR) for unsoaked condition with increasing cement/coal bottom ash content is an indication of the strength and stiffness of the soil-cement/coal bottom ash mixture. Also, WAS compaction gave then highest CBR value at 12:15% cement and coal bottom ash content.

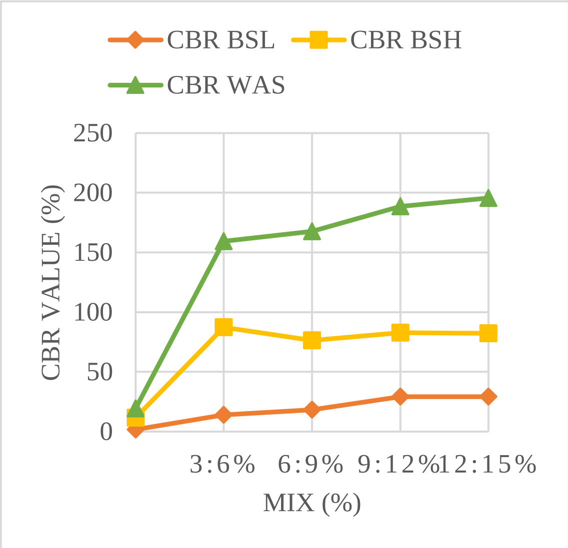

Figure 5: CBR value with %Cement and %Coal Bottom Ash

3.3.3 Unconfined Compressive Strength (UCS)

Figure 6 present the effect of cement and coal bottom ash on the Unconfined Compressive Strength (UCS) of the soil sample at 0 day for the three energy levels; BSL, WAS and BSH. The highest strength (563.11 kN/m^2 and 125.74 kN/m^2) for BSL and WAS compaction respectively was obtained at 6:9% cement and coal bottom ash content and 1318.62 kN/m^2 at 9:12% for BSH compaction was the highest strength of the three energy levels. Figure 7 present the effect of cement and coal bottom ash on the Unconfined Compressive Strength of the soil sample at 7 days of curing for the three energy levels. Generally, the strength of the soil sample improved gradually as the content of cement and coal bottom ash increased. Values obtained for BSH compaction were the highest of all the mixes at 7 days of curing from 188.94 kN/mm^2 for natural soil to 3648.41 kN/m^2 at 12:15% addition of cement/coal bottom ash. The trend at 7 days of curing repeated itself for curing at 28 days. The UCS values at 28 days are presented in Figure 8. Results of UCS obtained for the three-energy used indicate that higher compaction effort gave higher UCS value. Results of UCS for the three energy levels validate the potential of using cement and coal bottom ash to improve the strength parameters of subgrade.

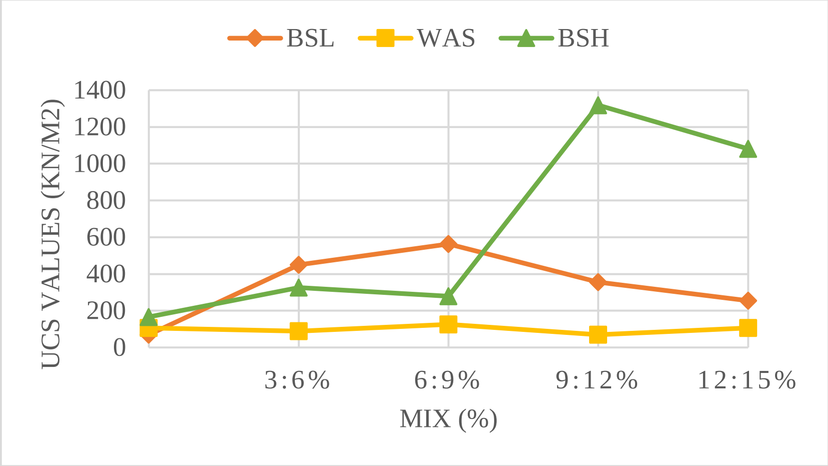

Figure 6: UCS with %Cement and %Coal Bottom Ash at 0 Day Curing

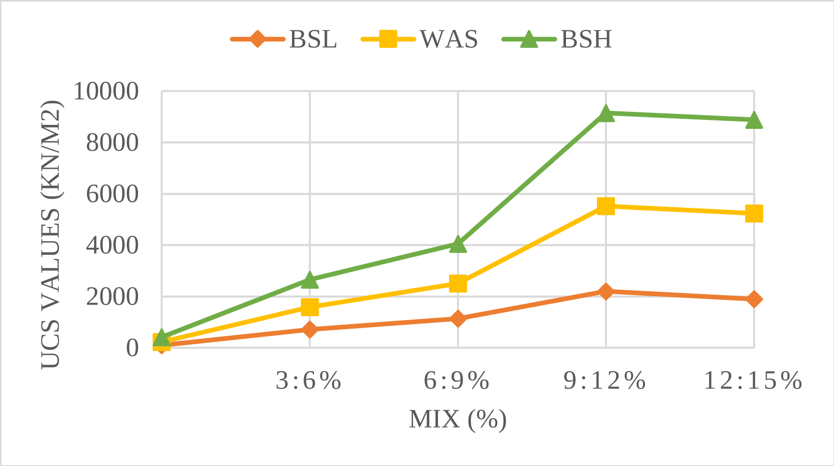

Figure 7: UCS with %Cement and %Coal Bottom Ash at 7 Days Curing

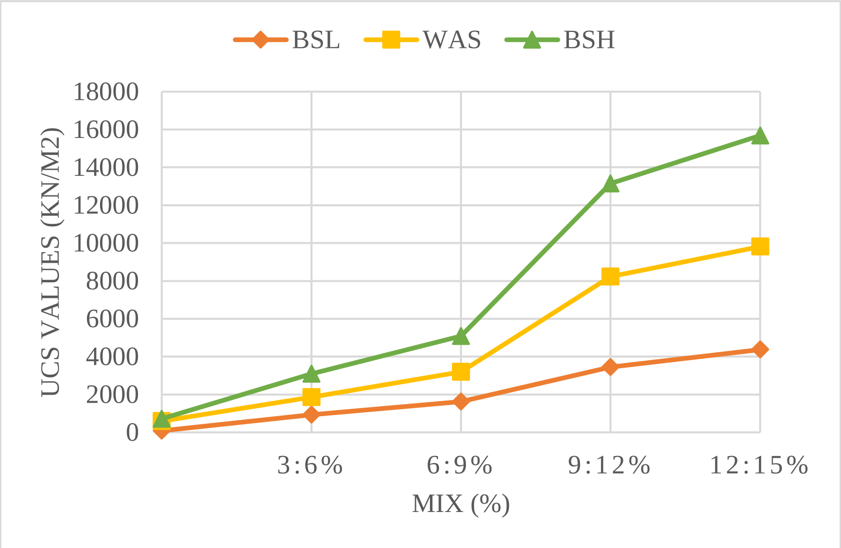

Figure 8: UCS with %Cement and %Coal Bottom Ash at 28 Days Curing

4.0 Conclusion

The research investigated the effect of adding up to 12:15% cement and coal bottom ash on the consistency limits, compaction characteristics, unconfined compressive strength and CBR soft clay. The following conclusions were drawn from the study;

- The natural soil is classified as A-7-6 according to AASHTO classification system and CL under Unified Classification System. The Liquid Limit increased with increasing cement and coal bottom ash content and Plasticity Index reduced with increasing percentage of cement and coal bottom ash. Plastic Limit increased from 25.32% for natural soil to 40.66% at 3:6% cement and coal bottom ash content and then returned to 0% at 6:9%, 9:12% and 12:15%.
- Addition of cement and coal bottom ash to the soil increased its swelling and shrinkage potential as liquid limit increased with increasing cement and coal bottom ash content as well as shear strength as plasticity index reduced with increasing cement and coal bottom ash content.
- Increasing cement and coal bottom ash content from 0 – 12:15% in the stabilized soil mixtures indicates a progressive increment in the MDD values for BSL, WAS and BSH. BSH gave the highest values of MDD which ranges between 1.77 – 1.83 g/cm^3 and corresponding OMC values between 16.00 – 21.50% for mixtures tested. However, for BSL and BSH compaction cement and coal bottom ash content at 3:6% gives the highest MDD at the respective energy level; WAS compaction highest MDD is achieved at 6:9%. Generally, the Maximum Dry Density (MDD) shows an increase with increasing compaction effort.
- Addition of cement and coal bottom ash to the natural soil shows improvement in the UCS values of the stabilized specimen. BSH gave the highest value of 5871.92 kN/m^2 for UCS at 28 days of curing. Therefore, addition of cement and coal bottom ash to the natural soil improves strength significantly for BSH and WAS compaction.
- Generally, addition of cement and coal bottom ash to the natural soil improved CBR values for unsoaked conditions based on the three compaction energy levels adopted in this research. Therefore, addition of cement and coal bottom ash to the natural soil significantly improved the stabilized soil load bearing capacity. This shows that cement and coal bottom ash has positive influence on the soil strength properties.
- This research work therefore established the potentials of using cement and coal bottom ash to improve the consistency limits, moisture – density properties and strength properties of A-7-6 soil for use in road pavement subgrade.

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