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Effects of Waste Glass (WG) on the Strength Characteristics of Cement Stabilized Expansive Soil

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Abstract:*The study investigates the suitability of using waste glass (WG) as admixture to cement stabilized black cotton soil (BCS) for roads, fills and embankment. The soil was classified as A-7-5 and CH according to the American Association of State Highway and Transport Officials (AASHTO) and the Unified Soil Classification System (USCS) Classifications. Chemical analysis revealed that WG is rich in main oxides such as Silicon Oxide (69.2), Aluminium Oxide (2.29), Iron Oxide (1.57), Calcium Oxide (15.1) and Sodium Oxide (8.75). The soil was stabilized with 0, 2, 4, 6 and 8% cement and 0, 5 10, 15 and 20% WG by weight of the dry soil. Laboratory tests were carried out using the Standard Proctor (SP) compactive efforts, California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), and compaction characteristics tests to evaluate the effectiveness of WG on Ordinary Portland cement (OPC) stabilized BCS. The results obtained showed a decrease in the plasticity index (PI), liquid limit (LL), plastic limit (PL) and increase Maximum Dry Density (MDD) with increase in WG content in all cement proportions used and as compared to the values obtained for the natural soil. The peak 7 days UCS values of 1152kN/m^2 was obtained at 8% OPC and 20% WG. Similarly, highest CBR value of 53.8% was obtained at an optimum blend of 8% OPC/20%WG. The results indicate that there is a potential in the use of WG as admixture to strengthen Black cotton soils.*
Keywords:*Black cotton soil, Waste Glass, Ordinary Portland cement*

I. Introduction

Black cotton soils (BCS) are clays or very fine silts that have a tendency for volume changes, to swell and soften or shrink and dry-crack, depending on the increase or decrease in moisture content.Black cotton soils (BCS) are found predominantly in the North-Eastern part of Nigeria, lying within the Chad Basin and partly within the Benue trough (Ola, 1981; NIBBRI, 1983; Osinubi et al, 2009).

The swell-shrink movements in expansive soils have historically caused frequent problems because of the unpredicted upward movements of structures or cracks in pavements resting on them. In addition, they also affect the serviceability performance of lightweight structures supported on them.These soils increase in volume on absorbing water during rainy seasons and decrease in volume when the water evaporates from them (Chen, 1988). The volume increase (swell) if resisted by any structure resting on it; then vertical swelling pressure is exerted by the soil on the structure. This pressure if not controlled, may cause uplifting and distress in the structure (Shelke and Murthy 2010). The strength loss on wetting is another severe problem with such soils. Due to this peculiar behaviour many civil engineering structures constructed on expansive soils get severely distressed. Pavements are in particular, susceptible to damage by expansive soils because they are lightweight and extend over large areas. Dwelling houses transferring light loads to such soils are also subjected to severe distress. Similarly, earth structures such as embankments, canals built with these soils suffer slips and damages (Mishra et al., 2008). The swelling and shrinking of the soil generate depressions, cracks and swelling of pavement constructed on it. Noticeable cracks which may result to failure are witnessed on buildings constructed on this type of soil, Costa and Baker (1981) reported that the damaging effect of these cracks is as high as 0.16 to 0.6 MN/m^2.It is therefore necessary to upgrade the engineering properties of deficient soils before they are put to use in construction.

Despite the proven performance of lime and Portland cement in the modification of the engineering and allied properties of problematic soils, the cost of blending soils with these stabilizers is usually prohibitive. In order to abate the cost of road base stabilization, one reasonable alternative is to mix the soil-lime or soil-cement blends with requisite amount of admixture (Matawal, *et-al*, 2006).

Glass is a hard material normally fragile and transparent common in our daily life. It is composed mainly of sand (silicate) and an alkali. It does not harm the environment in any way because it does not give off pollutants but it is non-biodegradable, once it is broken it can harm humans as well as animals if not dealt with carefully. It is regarded as useless and so discarded, littering the environment and constituting a nuisance in the community. The physical properties of the crushed glass are that they exhibit high permeability, high crushing resistance, small strain stiffness, and these properties could enhance its usage in geotechnical engineering works for soil stabilization, embankment constructions e.t.c.

Ideally, most waste glass would be recycled into new glass. However, since only colour sorted and contamination-free waste glass is feasible for reuse in the glass industry, there is a surplus of waste glass which cannot be reused by glass manufacturers. The increased amount of such waste being collected, which is surplus to current requirement will also need alternative uses. These portion deserve attention as the beneficial reuse of broken/crushed glass will reduce the space it takes up in our landfills enhancing our efforts to protect our environment.

Previous research work on waste glass had focused its use in concrete or asphalt paving materials (Shayan and Xu, 2004; Wu et al., 2003; Bignozzi et al., 2009; Byars et al., 2004; Nwaubani, 2013). Some researchers have studied the engineering properties of soil-crushed waste glass blend (Dennis et al., 2006; Grubb et al., 2006; Eberemu et al., 2012;) suggesting its suitability as an additive and as an admixture when used with standard stabilizers for highway pavement works; not much is known in literature about the geotechnical behavior of cement stabilized black cotton soil with waste glass admixture, hence the need for this study.

II. Materials

The Black cotton soils is obtained from Baurein villageYamaltu-Deba local government area of Gombe state, Nigeria. The waste glass (WG) used in this study was sourced from post-consumer waste, the glass was finely grinded, and an average particle size of < 300 μm was used. The BCS was classified as A-7-5 (AASHTO 1986) and CH (ASTM 1992). The properties of BCS is given in Table 1. The ordinary Portland cement (OPC) Ashaka brand, was obtained from the market,the chemicalcomposition of the BCS, WG and OPC compositions is presented in Table 2.

III. Experimental Methods

Laboratory tests were conducted in accordance with BS standard. The Atterberg limit tests, Standard proctor tests (SP), California bearing ratio tests (CBR) and unconfined compressive strength tests (UCS) were conducted in accordance with BS 1377(1990) and BS 1924 (1990).Compaction tests were conducted on BCS with varying percentages of OPC from 0%, 2%, 4%, 6% 8% and optimum mixes were obtained. After obtaining the optimum mix proportion, varying percentages of WG was added to the optimum mix of BCS-OPC from 5% - 20% at an increment of 5% by dry weight of the soil.The California Bearing Ratio (CBR) test was conducted on the BCS and OPC/WG stabilized BCS mixtures, the samples were compacted at their respective optimum moisture content in the CBR mould. Two set of each sample were prepared and subjected to un-soaked and soaked CBR test. The soaking was done for 48 hours.Unconfined compressive strength test was carried out on OPC/WG stabilized BCS samples,the samples were compacted at optimum moisture content using the SP energy level. Tests specimen are of specified height to diameter ratio in accordance with BS 1377, the cylindrical specimens used in this test are of diameter 38 mm and height 76 mm. After compaction, the OPC/WG stabilized BCS was extruded from the mold and sealed with double wrappings in polythene bags that were kept at a constant temperature of 25 ± 2˚C. This was done for various periods to allow for uniform moisture distribution and curing. After curing, specimen were placed in a load frame machine driven strain controlled at 0.10 %/min and crushed until failure occurred. Specimens were cured for 7, 14 and 28 days.The durability assessment of the soil stabilized specimens was carried out by immersion of 7 days cured UCS specimen in water for the measurement of resistance to loss in strength rather than the wet-dry and freeze-thaw tests highlighted in ASTM (Annual 1992). The resistance to loss in strength was determined as a ratio of the UCS values of sealed cellophane-cured specimens of 7 days, unsealed, and later immersed in water for another 7 days to the UCS values of 14 days cellophane –cured specimens.

IV. Results and Discussions

Atterberg limit

The liquid limit (LL) and plastic limit (PL) of the OPC/WG stabilized BCS have been determined in the laboratory in accordance with BS 1377 (1990). Figure 1 shows the variation of OPC/WG blend on the PI of the soil. It was observed that the PI decreased for a combination of OPC/WG blend up – to 20% WG. The highest decrease from 30.6% to 10.8% was recorded at 8% OPC / 20% WG blend. Similar trends for glass cullet dredged material blend was reported by Dennis et al., (2006) and Grubb et al., (2006).

Table 1: Properties of the Natural Soil

Natural moisture content (%)	24.43
Liquid limit (%)	65.5
Plastic limit (%)	34.9
Plasticity index (%)	30.6
Specific gravity	2.65
Percentage passing BS No. 200 sieve	80.2
Percentage Sand fraction	74
Percentage Silt fraction	16
Percentage Clay fraction	10
Activity	3.06
Maximum dry density (Mg/m^3)	1.4
Optimum moisture content (%)	27.7
Unconfined compressive strength (kN/m^2)	190
Soaked California bearing ratio (%)	9.4
Un-Soaked California bearing ratio (%)	10.6
Colour	Dark gray
AASHTO classification	A-7-5(13)
Group Index	13
USCS classification	CH
NBRRI classification	Medium swell

Table 2: XRF results of the BCS and WG

Compound	Concentration (%)	
	Soil	WG
Aluminium, Al	16.58	2.29
Silicon, Si	60.79	69.2
Potassium, K	1.39	1.10
Calcium, Ca	1.37	15.1
Manganese, Mn	0.08	0.02
Iron, Fe	6.13	1.57
Sodium, Na	0.16	8.75
Magnesium, Mg	1.17	0.49

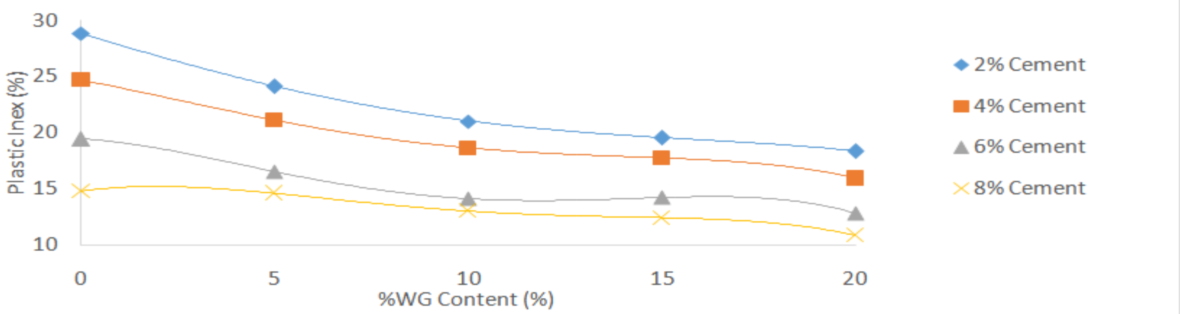

Figure 1: variation of PI of OPC stabilized BCS with WG content

Compactioncharacteristics

Effect of Compaction Condition on Dry Density and Water Content

The results obtained on the dry densities for the soil and soils treated with OPC and OPC/WG, showed that as the replacement levels of OPC and WG increase, the dry densities increase with the maximum value achieved at 20% replacement level for WG and at 8% replacement level for OPC. These behaviour are depicted in Figures 2 – 5 and showed that maximum dry densities for soil treated with 2-8% OPC is 1.61 Mg/m^3, while that of 2% OPC (5-20%WG), 4% OPC (5-20%WG), 6% OPC (5-20%WG) and 8% OPC (5-20%WG) is 1.62, 1.62, 1.62 and 1.63 Mg/m^3 respectively. The effects of the various replacement levels on the moisture contents, showed a divergent behaviour. As the replacement levels are increasing, the moisture content decrease which is an indication of better performance achieved at 20 % replacement level.

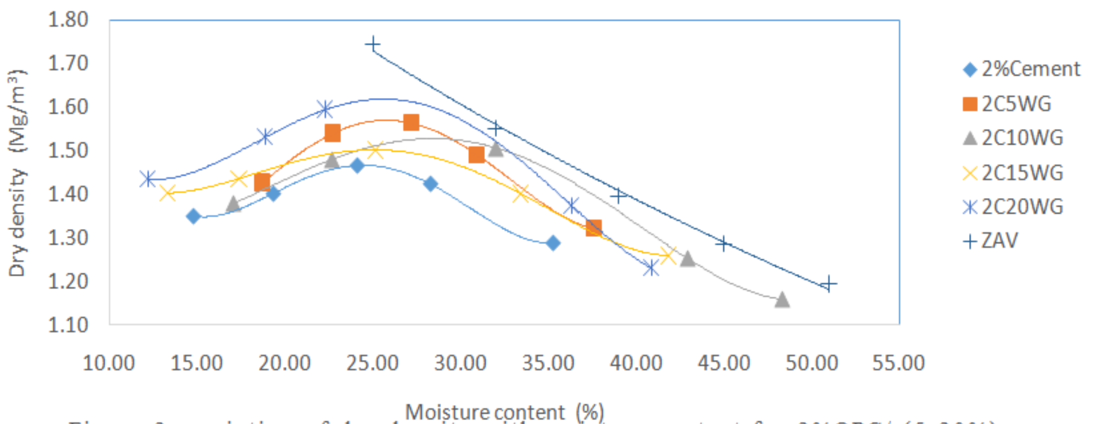

Figure 2: variation of dry density with moisture content for 2%OPC/ (5-20%) WG stabilized soil.

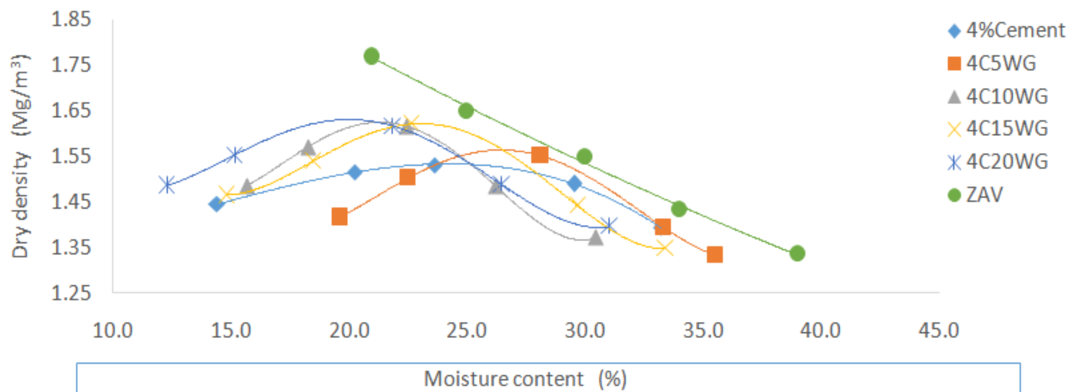

Figure 3: variation of dry density with moisture content for 4%OPC/ (5-20%) WG stabilized soil.

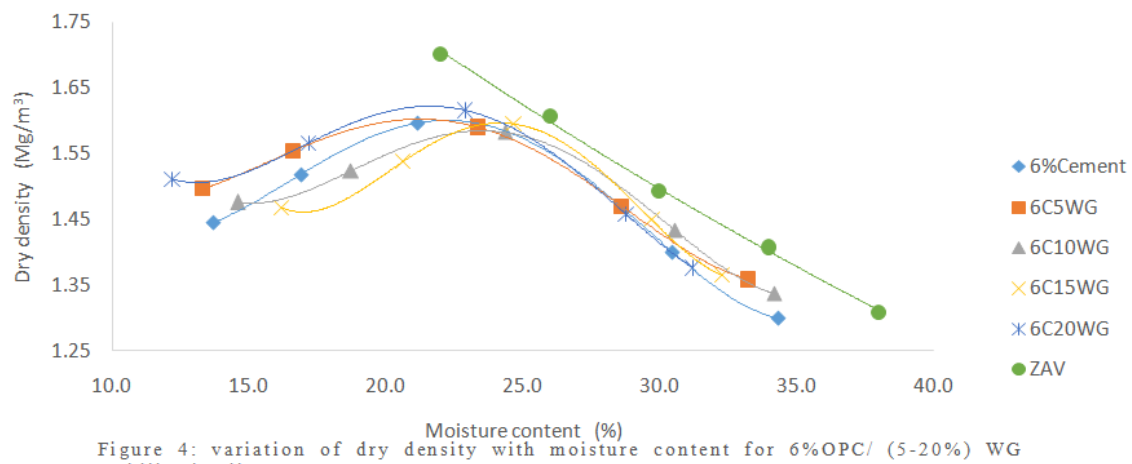

Figure 4: variation of dry density with moisture content for 6%OPC/ (5-20%) WG stabilized soil.

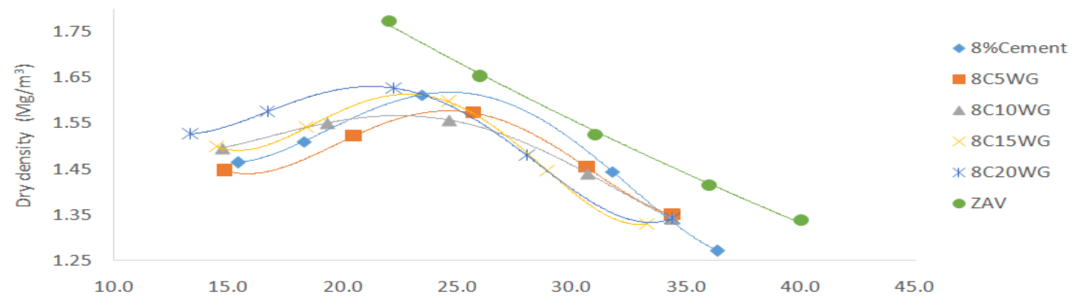

Figure 5: variation of dry density with moisture content for 8%OPC/ (5-20%) WG stabilized soil.

Effect of OPC/WG on maximum dry density and Optimum moisture content

On addition of WG to the soil/OPC mixture, an increase in MDD was observed with WG content. The increase in MDD was attributed to the formation of new compounds, increase in surface area of particles at higher dosage of OPC/WG blend, as well as improved workability of the soil due to the increase in the percentage of CaO in the mixture and the desiccating property of WG. Figure 6 shows the effects of OPC/WG blend on the MDD of the soil. Also, the addition of water causes the bulking phenomenon in the stabilized soil. The fine cement particles influenced the compatibility of soil-cement material as such the soil-cement interaction resulted in the cementitious products and it gained strength. This trend is in order and agrees with Arabani et al., 2012 who reported that increase in MDD is due to the basic fact that soil-cement mix might have difference in specific gravity than the original soil. The variations of OMC is shown in Figures 7. The OMC decreased with increase in OPC/WG blend, this may be attributed to the fact that the OPC/WG dosage increased the surface area of soil particles due to the alkali (Na_2O) content of WG in the formation of calcium silicate hydrates (C-S-H) for strength development of the treated soil, Khmiri et al., (2013).

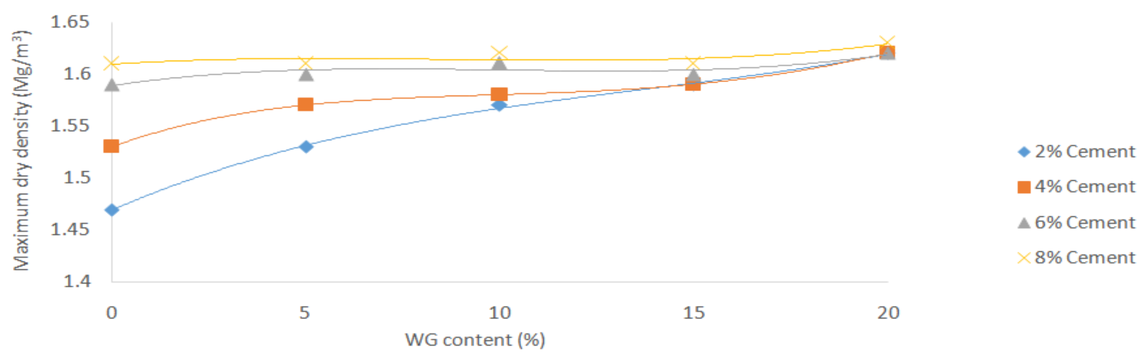

Figure 6: variation of MDD of OPC stabilized BCS with WG content.

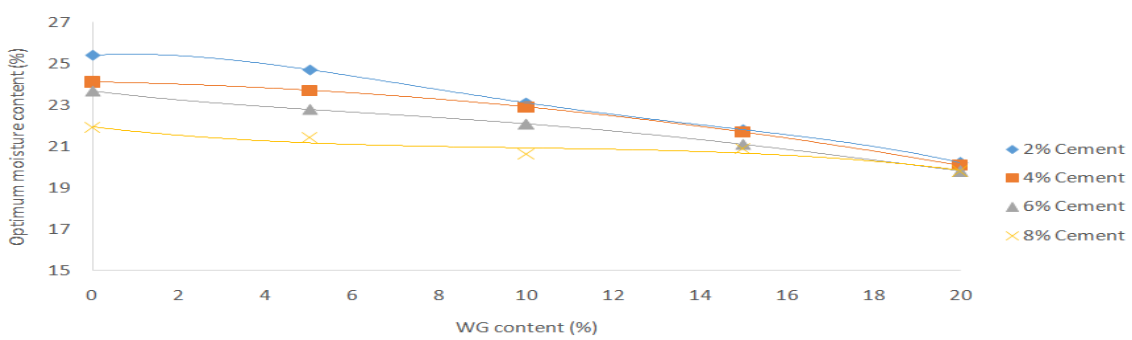

Figure 7: variation of OMC of OPC stabilized BCS with WG content.

Unconfined Compressive Strength

The variation of UCS with various percentages of OPC / WG blend after compacting the specimens at OMC for 7 days showed that compressive strength improved significantly after 7 days of curing. However, the peak 7-day UCS value of 1152 kN/m^2 was recorded at 8% OPC / 20% WG blend, as shown in figure 8. The TRRL (1977) specified 1720 kN/m^2 as criterion for adequate stabilization using OPC. The influence of compactive effort on the compressive strength of the 7 days cured specimens is well pronounced for each of the blend tested.

The variations of UCS for the samples cured for a period of 14 daysis shown in Figure 9, the influence of WG admixture on the compressive strength has a long-term effect which may be attributed the slow pozzolanic chemical reaction with WG and calcium hydroxide (CH) of cement when compared with OPC hydration. This agreed with the assertion of Dyer and Dhir (2001). The long-term chemical reaction progressively increases the strength of the mix. The UCS value of 1257 kN/m^2 obtained for a combination of 8% OPC/10% WG was noticeably higher than the UCS values obtained for ″OPC alone″ treated specimens. It could therefore be inferred that the compressive strength increased linearly by fixing the OPC content and varying WG content from 5-20%. The increase in the compressive strength may be attributable to the concentration of OPC in this range, which reduces plasticity, thereby improving cementatious properties of the soil. It is evident that the OPC/WG content, curing age, as well as the rise in the pH level of the soil gives rise to strength development of the specimens.Figure 10 shows the specimen cured for 28 days. The results illustrated that at 4, 6 and 8% OPC the compressive strength decreased with higher dosage of WG admixture. However, at 2% OPC content the strength increase with higher concentration of WG. Which agreed with Ingles and Metcalf (1972). Higher strength was archived at 8% OPC / 5% WG blend, this may be due to pozzolanic reaction, which progressively enhances the strength of the treated soil. The development of high UCS values at the 28-day curing period is attributed to the effect of OPC which promote the production of alkaline compounds that increases the pH value of the soil and promote the self-hardening Characteristics of the WG admixture.

By Comparing the 28 days strength with those obtained at 7 and 14 days, it is obvious that the lower values obtained at 7 and 14 days were as a result of premature failure of the specimens (splitting of ends and spalling of the surface). Also, Wartman et al. (2004) suggested that the impact of WG on strength of fine grained soils may be delayed until WG particles cease floating in the fine grained matrix and develop particle to particle interactions which subsequently dominate the strength behavoir.

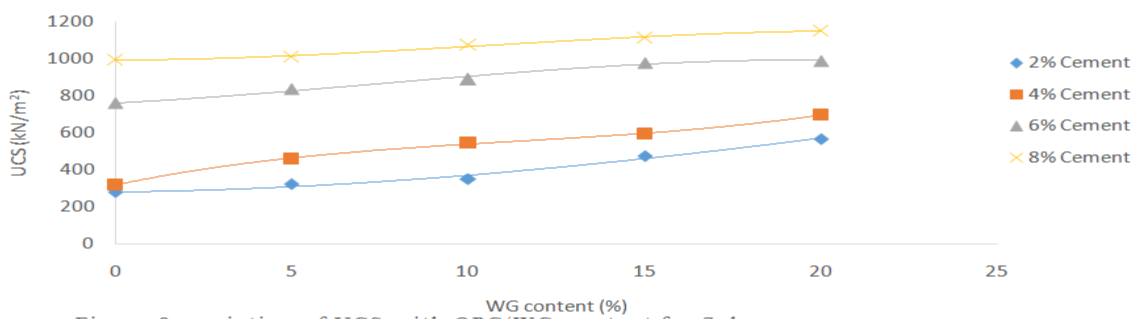

Figure 8: variation of UCS with OPC/WG content for 7 days.

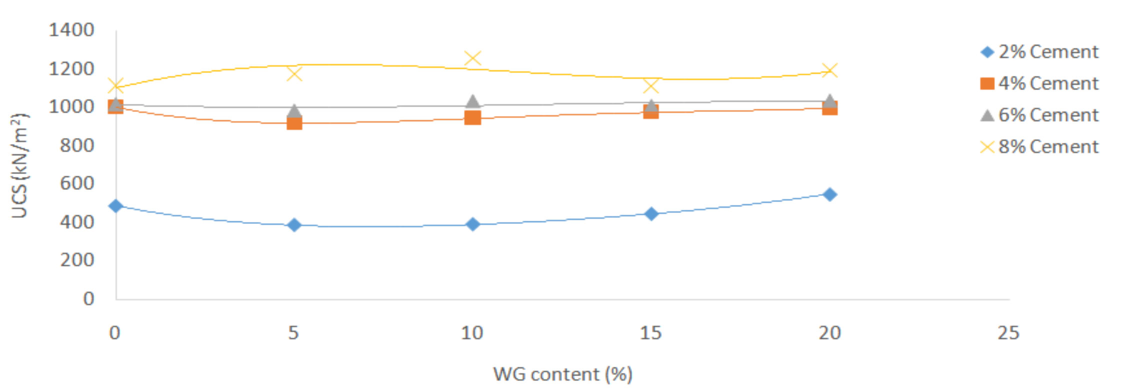

Figure 9: variation of UCS with OPC/WG content for 14 days.

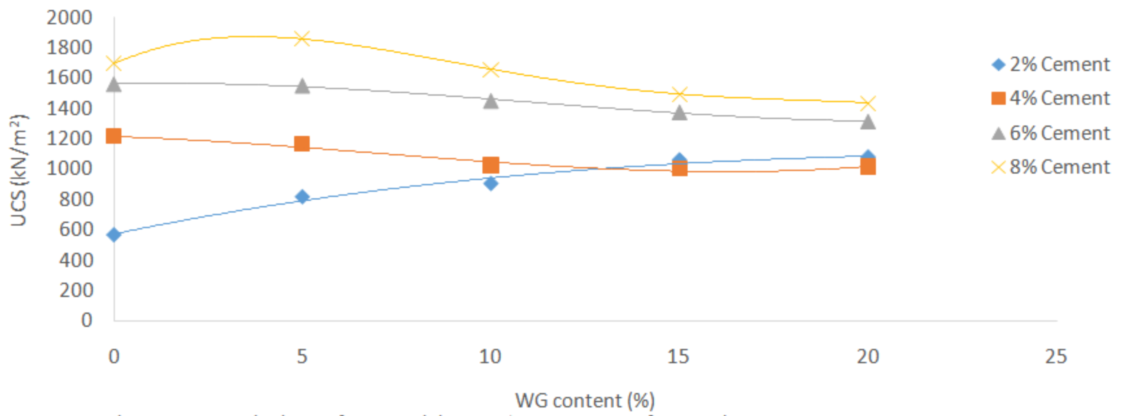

Figure 10: variation of UCS with OPC/WG content for 28 days.

California Bearing Ratio

Figure 11 shows the variation of un-soaked CBR with various percentages of OPC/WG blend. The CBR value of the specimen treated with OPC only increased with increase in OPC content, with the addition of WG, the CBR value increased at higher percentage of WG. This may be attributed to the increase in the contact area and adhesion between OPC and soil by WG which will create a dense network of interconnected particles, an increase of about 407.5% in the CBR value was noticed at 8% OPC/20%WG blend.

Arabani et al., (2012), in their study of cement stabilized with crushed glass sand blends reported that the cementitious reaction between cement and blends took place as a primary process. The hydration of the cement was regarded as primary reaction and formed the normal hydration products that bound particles together. The increase in the CBR value may be due to the shear transfer mechanism between the soil and WG, and the improvement in the strength might be due to the pozzolanic action of WG/OPC mix. Furthermore, the peak CBR value of 39%, with 0%WG content did not meet the 180% CBR value criterion recommended by the Nigerian General Specification (1997) for OPC stabilized soil. This is attributed to the high content of montmorillonite in the soil, which seems to negate the effectiveness of OPC.

However, specimens treated with 8% OPC/ (5-20%) WG meet the requirement of 30% CBR of the Nigerian General Specification (1997) for use of the soil material for sub-base in roads, other mixes also met this requirement, and they include 6% OPC / (5-20%) WG, 4% OPC /20% WG compacted at MP energy level and 6% OPC / (15-20%) WG compacted at SP energy level

However, at 2, 4 and 6% OPC with varying proportions of WG compacted with both compactive effort did not meet the requirement for good quality base or sub-base for road pavement, it however, suffices for use as a sub-grade material.

Durability of CBR Specimens

The variation of soaked CBR with WG is shown in figure 12. It is observed that 48 hours soaking period did reduce the CBR values, but the soil may not be suitable for use as a base or sub-base material. This could imply that prolong soaking of the specimens might give lower CBR values.

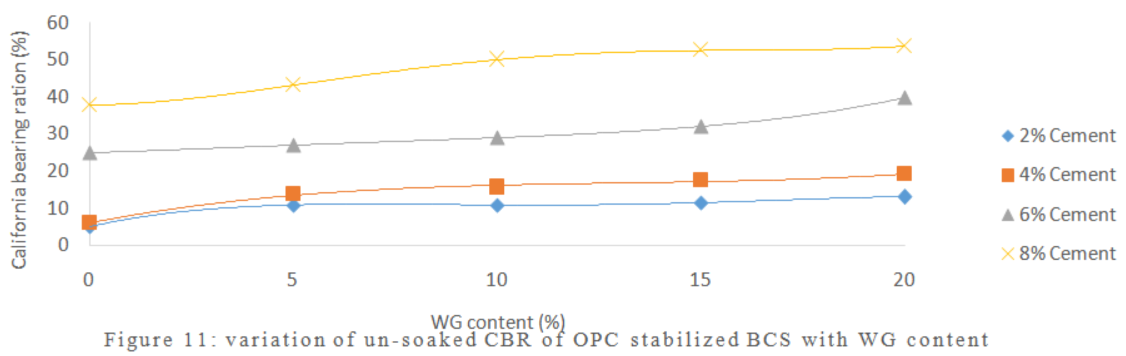

Figure 11: variation of un-soaked CBR of OPC stabilized BCS with WG content

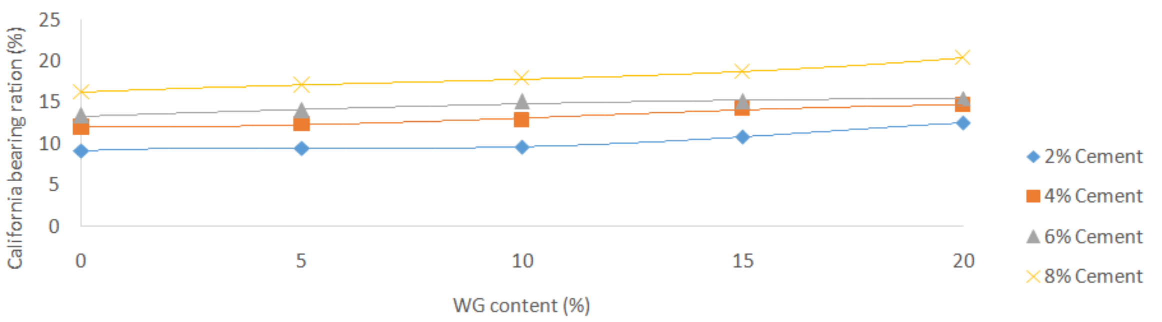

Figure 12: variation of soaked CBR of OPC stabilized BCS with WG contet

Conclusions

From the experimental results of the investigations, the following conclusions can be made:

i. The addition of WG resulted in the reduction of plasticity index, thus given rise to greater workability when compared to untreated clays.
ii. The addition of WG resulted in a reduction in Optimum Moisture Content and increased the Dry Density of cement stabilized BCS with WG content for Standard and Modified compactive efforts.
iii. The results also showed that WG may be substantially used to improve the Unconfined Compressive Strength (UCS) of treated soils.
iv. The CBR values obtained for the OPC/WG stabilized soils gave higher values obtained for the untreated soil.

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