ASSESSMENT OF SUBGRADE SOIL STABILIZED WITH CALCIUM CARBIDE WASTE, CEMENT KILN DUST AND STEEL SLAG

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ABSTRACT

Poor subgrade soil conditions can result to inadequate pavement support and reduce pavement life and such soil may be improved through the addition of chemical or cementation additives. This paper present assessment of weak subgrade stabilized with Calcium carbide waste (CCW), Steel slag (SS) and Cement kiln dust (CKD) in terms of Plasticity Index (PI), Maximum dry density (MDD), California bearing ratio (CBR) and Unconfined Compressive Strength (UCS). Curing was done in accordance with relevant specification for stabilized soils at 0, 7, 28, and 90 days. The result indicate that beyond 6% CCW shows no change in PI, thus 6% CCW can be designated as fixation point which was used to activate the pozzolanic effect of SS while the optimum value for CKD was at 15%. MDD decreases with increase in percentages of 0 – 20% CKD from 1.88g/cm^3 to 1.74g/cm^3 while it increases with increase in SS. Maximum CBR was achieved at 8% CCW corresponding to 111,119, 167 and 235% and CKD (15%) are 86, 96, 133 and 176% for 0, 7, 28, and 90 days respectively. UCS for SS and CKD at their optimum value for 7, 28 and 90 days were 1296.38, 1654.28, 2198.95 kN/m^2 and 1148.04, 1364.38, 1800.99 kN/m^2 accordingly. The CBR and UCS results showed that the stabilized soil at 7 days curing can be used as a sub-base material for pavement construction.

Keywords: *subgrade, cement kiln dust, plastic index, unconfined compressive strength, California bearing ratio, steel slag,*

INTRODUCTION

Subgrade soils encountered during road construction are not always good materials to respond to the imposed stresses which has become a dominating factor for the failure of pavements in Nigeria (Aigbedion, 2007). Improving the properties of these soils by addition of chemicals and cementitious additives make them suitable for construction. The high cost and energy-intensive process of Portland cement usage are, however, the driving force to source for alternative cementitious additives. Clayey soils material with high natural pozzolanic materials, calcium hydroxide materials can be used as alternating cementing agent to produce moderately high strength geo-materials (Apichit *et al*., 2014). The cementing property is identified as a pozzolanic reaction. The engineering characteristic of calcium hydroxide rich stabilized soil clay materials are attributed to cation exchange, flocculation and aggregation, and the pozzolanic reaction.

Addition of calcium hydroxide rich material to clayey soil supplies an excess of Ca^{2+}, and the cation exchange will occur with Ca^{2+} replacing dissimilar cations from the exchange complex of the soil, causing flocculation and aggregation of the clay fraction. The clay particles clump together into larger sized aggregates. Influence of cation exchange, flocculation and aggregation are responsible for the change in plasticity and shrinkage (Horpibulduk *et al*., 2012). Strength of the stabilized soil gradually increases with curing time due to the pozzolanic reaction. Calcium hydroxide can react with the silicates and aluminates in the clay to form cementitious materials, consisting calcium aluninates silicates hydrates (Apichit *et al*., 2014; Horpibulduk *et al*., 2012).

Calcium carbide waste (CCW) is a by-product of the acetylene production process that contains calcium hydroxide, has been used for soil stabilization (Horpibulsuk *et al*., 2012; Horpibulsuk *et al*., 2013; Kampala & Horpibulsuk, 2013). Engineering characteristics of calcium carbide residue stabilized clay was evaluated by Horpibulsuk *et al*., 2012, 2013) and Kampala & Horpibulsuk (2013) to ascetained the performance in fill and pavement applications. They confirmed that the calcium carbide residue is more effective than the lime stabilization in terms of engineering, economical, and environmental view points. Cement kiln dust (CKD) is a fine powdery material similar in appearance to Portland cement in the kiln during production of cement clinker. The dust is a particulate mixture of partially calcined and unreacted raw feed clinker, clicker dust and ash, enriched with alkali, sulphates, halides and other volatiles. The use of CKDs as soil stabilizers might potentially consume the bulk of CKD being generated every year as well as enhancing the engineering characteristics of unsuitable and marginal soils. Brijesh & Nitish, (2013) studied the possibility of using CKD to stabilize weak pavement subgrade in the range of 5-25%. The California bearing ratio (CBR) test shows that the value increases with increase in CKD and Unconfined compressive strength (UCS) up to 20%. Steel slag (SS) is a by-product of steel making from separation of molten steel from impurities. American Society for Testing Materials defined steel slag as a non-metallic product, consisting essentially of calcium silicates and ferrites combined with fused oxides of iron, aluminum, manganese that are developed simultaneously with steel in basic oxygen, electric arc or open hearth furnaces. Akinwumi (2012) utilized steel slag in improving the plasticity, UCS and drainage characteristics of lateritic soil. The study showed that the improvement of the soil was limited to application of 8% steel slag. This paper assess the role of CCW, CKD and SS on the strength development of weak subgrade via unconfined compressive strength and California bearing ratio tests.

MATERIALS AND METHODS

Subgrade soil sample was collected from a section of Lafenwa road (latitude $3^0$19’33,2” and longitude $7^0$9’20.32”) in Abeokuta, Ogun State during road construction at 1.5 m depth. The soil was stored in polythene bags and taken to Department of Civil Engineering Laboratory and Pavement Evaluation Unit of Federal Ministry of Works, Ikoyi Lagos for tests. The grain size distribution of soil shows that the soil is composed of 4.4% gravel, 87.5% sand and 8.1% fines. Its specific gravity is 2.52 while the liquid and plastic limits are 43% and 27% respectively. According to Unified Soil Classification System and American Association of State and Highway Traffic Officials (AASHTO) the soil is classifed as well graded and with clay (SW-SC) and A-2-7 respectively. The geotechnical properties and grain size distribution curve of the soil sample are shown Table 1 and Fig. 1 respectively. CCW was collected at mechanic village at Camp road, Abeokuta (latitude $3^0$26’6.92”and longitude $7^0$11’14.83”) dried in an open air and passes through 0.425 mm sieve. CCW that passes through the sieve was used to modify the soil index property and to activate the pozzolanic property of steel slag. CKD and SS were obtained from Lafarge Cement company, Shagamu and Top Steel Company, Odogunyan Shagamu respectively. The materials was passed through 0.425 mm sieve and the retained material was discarded. CCW was added at 2, 4, 6, 8 and 10% to the soil sample to determine the fixation point through Atterberg test i.e. the point at which the changes in plasticity index is insifignicant. The percentage of CCW was found to be 6% (fig. 2). CKD and SS was added to the soil sample at 10, 15, 20, 25% and 4, 8, 12 16% respectively. Atterberg limits and Compaction characteristics of the virgin and stabilized soil was carried out using modified Proctor energy. After, 24 h of compaction, the stabilized samples were dismantled from the mould, wrapped in polythene bags, and stored in a humidity chamber of constant temperature of 25^0C. The UCS and CBR tests was performed on the stabilized soils after 7, 28 and 90 days of conforming to the ASTM standards to assess the strength development. Table 2 summarizes the testing program for the soil samples considered.

Table 1: Geotechnical Properties of Virgin soil

PROPERTIES	VALUES
Natural Moisture Content (%)	22.50
Specific Gravity	2.52
Liquid Limit (%)	42.50
Plastic Limit (%)	26.97
Plasticity Index (%)	15.53
AASHTO Soil Classification System	A-2-7(0)
Unified Soil Classification System	SW-SC
Maximum Dry Density (g/cm^3)	1.88
Optimum Moisture Content (%)	15.18
Soaked California Bearing Ratio (CBR) Value (%)	3.27
Unconfined Compressive Strength (UCS) Value (kN/m^2)	185.41
Colour	Light Grey

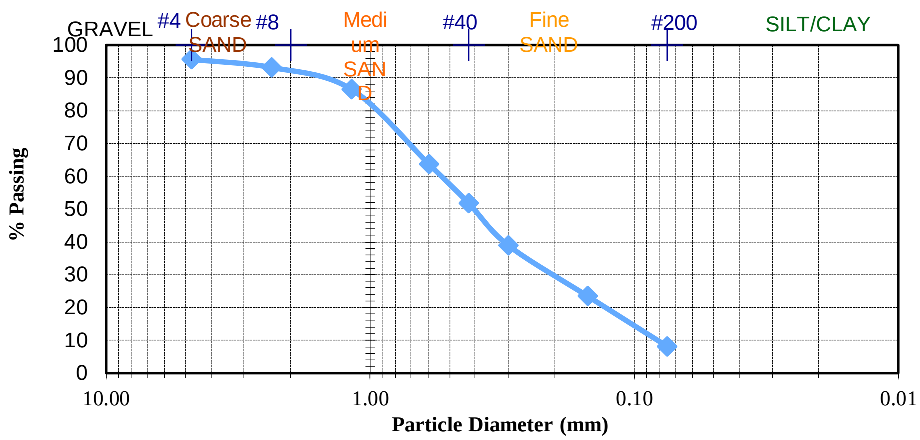


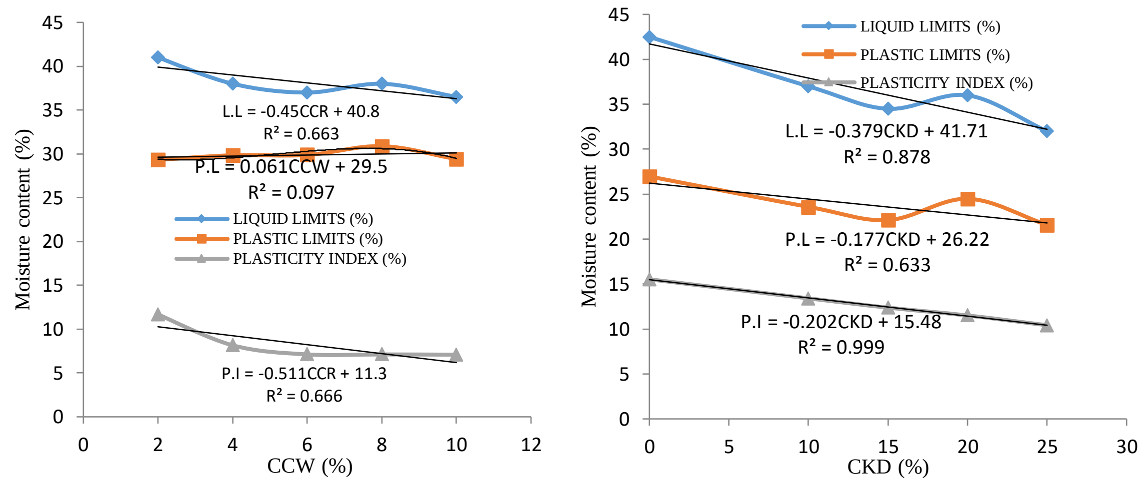
Figure 1. Grain size distribution

Table 2. Summary of Testing Program

Test	Binder (%)	Curing time (days)	CCW/SS/CKD content
PI	CCW	-	2, 4, 6, 8 & 10
Compaction	CCW+SS	-	4, 8, 12 & 16
	CKD	-	0, 10, 15, 20 & 25
CBR	CCW+SS	0, 7, 28, & 90	4, 8, 12 & 16
	CKD	0, 7, 28, & 90	0, 10, 15, 20, & 25
UCS	CCW+SS	0, 7, 28, & 90	4, 8, 12, & 16
	CKD	0, 7, 28, & 90	0, 10, 15, 20, & 25

RESULTS AND DISCUSSION

The average specific gravity of CKD and SS are 2.47 and 3.26 respectively, the CKD falls out of range specified by Baghdadi (1990) while SS lies within the range of 3.2 and 3.6 as reported by TFHRC (2011). Figures 2 shows the variations in index properties for CCW and CKD, figure 2a shows that as the CCW content increases, the plastic limit (PL) of the stabilized soil sample slightly increases while liquid limit (LL) decrease resulting in a decrease in the plastic index (PI). This decrease in PI indicates the flocculation of clay particles, which is caused by the adsorption of Ca^{2+} ions from the cation exchange process (Horpibulsuk *et al.*, 2012). However, beyond 6% CCW shows no change in PI, this indicate that the maximum adsorption capacity of the of Ca^{2+} ions by silty clay occurs at 6%. This point can be designated as CCW fixation point which was used to activate the pozzolanic effect of SS. This result obtained when compared with Horpibulsulk (2012) shows that it is slightly lower which can be attributted to the difference in the percentage of clay content present in the soil sample considered. Figure 2b showed that liquid limit decreases with increase of CKD up to 15%, then increase slightly before decreasing with addition of CKD. This initial reduction could be attributed to cementitious properties of CKD due to high content of calcium oxide which aid the flocculation and aggregation of soil particles. The optimum content of CKD to stabilize the soil sample was 15%, resulting in a reduction of LL, PL and PI which was similar to work reported by Ismaiel (2013). The results of the compaction characteristics of the stabilized soil are presented in Table 3, maximum dry density (MDD) decreases with increase in percentages of 0 – 20% CKD from 1.88g/cm^3 to 1.74g/cm^3. This can be attributed to the lower specific gravity of CKD and the trend is in agreement with the work of Keerthi *et al.*, (2013) and Kuldip *et al.*, (2014). Contrary result was observed when SS was added to the soil sample, MDD increases with increase in SS which was consistent with the observation reported by Biradar *et al*., (2014). Moreover, the increase can be explained in terms of the SS specific gravity of 3.26 compared to the soil sample of 2.52.



(a) (b)

Figure 2 Relationship between Atterberg's limit and Binder

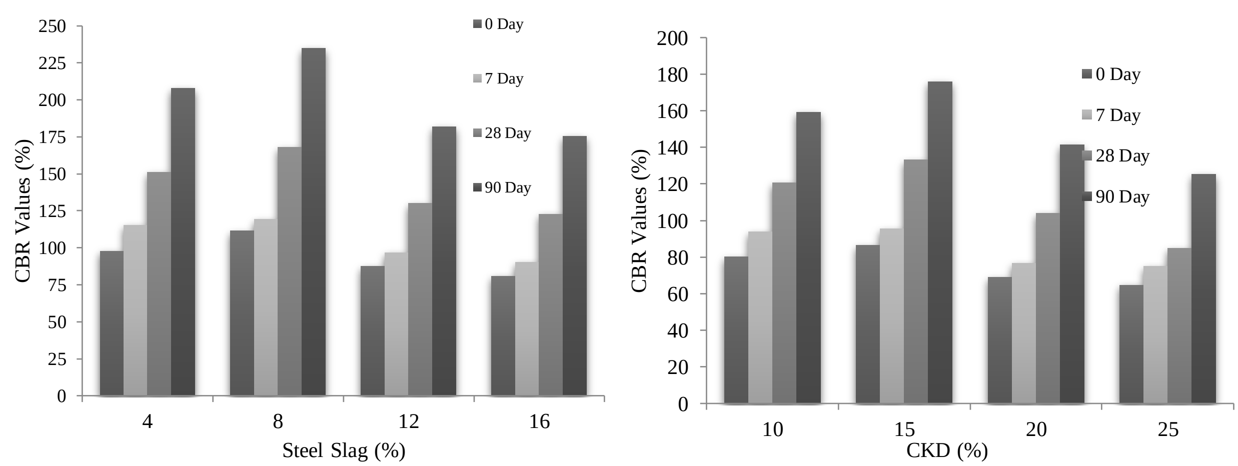
Table 3. Compaction Characteristics

S/N	CKD (%)	MDD (g/cm^3)	OMC (%)	SS (%)	MDD (g/cm^3)	OMC (%)
1	0	1.88	15.18	0	1.88	15.18
2	10	1.79	18.71	4	1.90	14.84
3	15	1.77	19.09	8	1.92	14.63
4	20	1.74	20.78	12	1.93	14.48
5	25	1.76	21.03	16	1.95	14.28

Effect of Curing time on CBR of Soil-Steel Slag and Soil-CKD

The CBR results of the soil stabilized with SS is illustrated in the figure 3a, the maximum soaked CBR was achieved at 8% SS corresponding to 111, 119, 167 and 235% for 0, 7, 28 and 90 days respectively. The gain in strength of the stabilized soil with age is attributed to long-term hydration reaction that resulted in the formation of cementitious compound (Yadu & Tripathi, 2013).

Figure 3b shows the variation of soaked CBR with increase in CKD, CBR increases with increase in curing time up to 15% CKD and beyond this value decrease in CBR was observed. The CBR for the virgin soil (3%) increased in strength at 15% CKD to 86, 96, 133 and 176% for 0, 7, 28 and 90 days respectively.

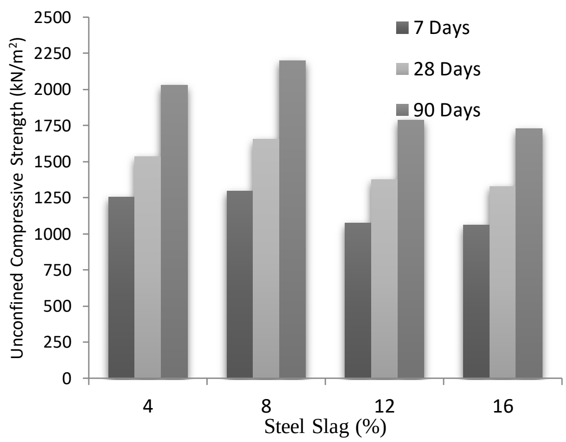


(a) (b)

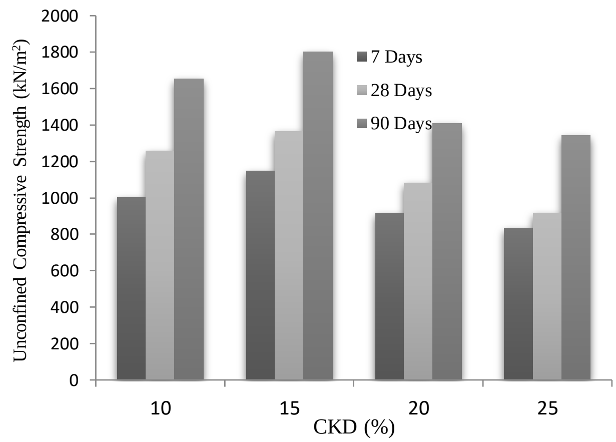
Figure 3 Relationship between CBR and Stabilized Soil

Effect of Curing time on UCS of Stabilized Soil

The results of UCS with curing time for soil stabilized with SS and CKD are summarized in figure 4. There was an increase in UCS with curing time up to 8% SS and 15% CKD. UCS for SS and CKD at their optimum values for 7, 28 and 90 days are 1296.38, 1654.28, 2198.95 kN/m^2 and 1148.04, 1364.38, 1800.99 kN/m^2 respectively. The increase in the UCS values was primarily as a result of the formation of various compounds such as calcium silicate hydrates and calcium aluminate hydrates (Horpibulsuk *et al.*, 2012a; Horpibulsuk *et al*., 2013). The UCS results obtained for 7 day curing falls within the specification of sub-base (750-1500 kN/m^2) as highlighted by FMW (2013).



(a)



(b)

Figure 4 Relationship between UCS and Stabilized soil

CONCLUSION

This paper present the analysis of strength development in subgrade soil stabilized with calcium carbide waste, cement kiln dust and steel slag in terms of California bearing ratio and unconfined compressive strength. The following conclusion can be drawn:

1. There was no significant change in PI beyond 6% CCW therefore the CCW fixation point is 6% while the optimum value for CKD was at 15%.
2. Maximum CBR was achieved at 8% CCW corresponding to 111,119, 167 and 235% at 0, 7, 28, and 90 days respectively
3. CBR for CKD stabilized soil at 15% for 0, 7, 28 and 90 days are 86, 96, 133 and 176% respectively
4. UCS for SS and CKD at their optimum value for 7, 28 and 90 days were 1296.38, 1654.28, 2198.95 kN/m^2 and 1148.04, 1364.38, 1800.99 kN/m^2 respectively
5. The CBR and UCS results showed that the stabilized soil at 7 days curing can be used as a sub-base material for pavement construction

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