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Influence of Compactive Efforts on Compacted Foundry Sand Treated With Cement Kiln Dust

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Laboratory tests were carried out on foundry sand treated with up to 12% cement kiln dust (CKD) by dry weight of soil to determine its suitability for use as road pavement material. Specimens were compacted at the energy levels of Standard Proctor (BSL), West African standard (WAS) and British standard heavy (BSH). The foundry sand utilized in this study is classified as A-2(0) or SM using the America Association of Highway and Transportation Officials (AASHTO) and the Unified Soil Classification System (USCS), respectively. The 7day unconfined compressive strength (UCS) values recorded for the natural soil at BSL, WAS and BSH compactive efforts record values of 165, 316 and 344 kN/m^2 respectively, while peak values of 416, 378 and 444 kN/m^2 were recorded at 8 % CKD, 6 % CKD and 6 % CKD treatments of foundry sand, respectively. None of the Specimens attained the UCS value of 1710 kN/m^2 conventionally used as criterion for adequate cement stabilization. California bearing ratio values recorded for the untreated foundry sand at BSL, WAS and BSH compactive efforts are 4, 6 and 8%, respectively. While peak California bearing ratio values of 15, 20 and 52% were recorded at 12% CKD treatments for BSL, WAS and BSH compactive effort respectively. The CBR values of 20 and 52% at treatment level of 8% CKD for WAS and BSH compactive effort satisfy the recommended minimum CBR value of 20-30% when compacted at optimum moisture content and 100% West African standards for sub-base material. The durability of specimens determined by immersion in water failed to produce an acceptable loss in strength value of less than 20% as specified for tropical soils.

Keywords: Cement Kiln Dust, Compacted Durability, California bearing ratio, Unconfined Compressive strength,

1. Introduction

Research into new and innovation use of waste material is continually being advanced, particularly concerning the feasibility, environmental suitability and performance of the beneficial reuse of most waste materials. In order to make soil useful and meet foundation engineering design requirements, since the cost of procuring materials that meet specification requirement are increasingly becoming uneconomical, researches have been intensified with the aim of using admixtures/additives to reduce the cost of procuring cement and other stabilizing agents.

2. Theoritical Background

There are basically two types of pozzolanas, namely natural and artificial pozzolanas. Natural pozzolanas are essentially volcanic ashes from geologically recent volcanic activity (Cook, 1986; Shi and Day, 1995; Mertens et al., 2009). Artificial pozzolanas result from various industrial and agricultural processes, usually as by-products. The most important artificial pozzolanas are burnt clay, pulverized-fuel ash (PFA), ground granulated blast furnace slag (GGBFS) and rice husk ash (RHA). These admixtures (fly ash, cold bottom ash, crushed concrete powder, bagasse ash and blast furnace slag and phosphoric waste) have been employed in research works (Osinubi et al., 1997, 2008; Toro, 1997; Osinubi and Stephen, 2005, 2006a,b, 2007, 2008; Osinubi and Medubi, 1997;.Osinubi and Katte, 1997; Osinubi and Mohammed, 2005; Osinubi, 1995,1998a,b, 1999 2000, 2006). Considerable amount of research has been conducted on the use of CKD as a medium for dewatering and stabilizing raw or digested sewage and treatment of sludge (Burn ham et al, 1990; Kovaciki, 1988; Metry, et al 1985; Zier and Wood, 1991). It has been used in improving soil strength, hence as an alternative for soil stabilization as opposed to lime (Miller and Zaman, 2004). The improvement of soil strength using cement kiln dust as a stabilizer has been reported by Bujang (1998).

Cement kiln dust (CKD) is an industrial waste from cement production. The quantities and characteristics of CKD generated depend upon a number of operational factors and characteristics of the inputs to the manufacturing process. Although the relative constituent's concentrations in CKD can vary significantly, CKD has certain physical characteristics that are relatively consistent (Kohlhaas et al., 1983). When stored fresh, CKD is a fine dry, alkaline dust that readily absorbs water. The ability of the CKD to absorb water stems from its chemically dehydrated nature, which results from the thermal treatments it receives in the system. the action of absorbing water (rehydrating) releases a significant amount of heat from non-weathered crust, a phenomenon that can be exploited in beneficial re-use in order to improve the inadequacy of some construction material.

There are two basic types of foundry sand available, green sand (often referred to as molding sand) that uses clay as the binder material, and chemically bonded sand that uses polymers to bind the sand grains together. Green sand consists of 85 – 95% silica, 0 – 12% clay (bentonite, kaolin etc), 2 – 10% carbonaceous additives, such as sea coal, and 2 – 5% water, other minor ingredients (flour, rice hulls, starches, cereals, etc.) may be added to absorb moisture, improve the fluidity of the sand, or stiffen the sand based on the production needs of the individual foundry. Green sand is the most commonly used molding media in foundries. Large quantities of waste materials from mineral, agricultural, domestic and industrial sources are generated daily and the safe disposal of these wastes are increasingly becoming a major concern around the world (ETL, 1999). These wastes, if properly treated, could be modified for use as structural components of highway pavements or as waste containment materials.

However, limited work has been reported on the the influence of compactive efforts on compacted foundry sand treated with cement kiln dust for road pavement applications. This study is aimed at evaluating of the influence of compactive efforts on compacted foundry sand treated with cement kiln dust

3. Materials and Methods

3.1 *Materials*

3.1.1 *Foundry sand***:** The foundry sand used in this study was obtained from Defense Industries Corporation of Nigeria (DICON), Kaduna (Latitude 10°30'N and Longitude 7°27'E), Nigeria.

3.1.2 *Cement Kiln Dust*: The cement kiln dust used was obtained from freshly deposited heaps of the waste at the Ashaka cement production plant located in Nafada Local Government Area of Gombe state, (Latitude 0° 19'N and Longitude11° 30'E), Nigeria. The CKD is brownish in color with a specific gravity of 1.90. The CKD was sieved through BS sieve No. 200 and was stored in air-tight containers before usage (Table 1).

3.2 *Methods*

3.2.1 *Index Properties*

Laboratory tests were conducted to determine the index properties of the foundry sand and foundry sand– cement kiln dust mixtures in accordance with British Standards BS 1377 (1990) and BS 1924 (1990) respectively. Index properties of foundry sand– cement kiln dust mixtures are shown in Table 2. A summary of the soil index properties is presented in Table 2.

3.2.2 *Compaction*

All the compactions involving moisture-density relationships, CBR and UCS were carried out at energies derived from the standard Proctor (BSL), West African Standard (WAS) and modified Proctor (BSH). The BSL is a low energy level and BSH is a high energy level and they are widely used. However, the WAS compactive effort is the conventional energy level commonly used in the West African region, and when compared with the BSL and BSH compactive effort, its energy level is intermediate. The mixes consisted 0, 4, 8 and 12% CKD by dry weight of soil. The BSL compactions were carried out using energies derived from a rammer of 2.5 kg mass falling through a height of 30 cm in a 1000 cm^3 mould. The soil was compacted in three layers, each receiving 27 blows. The soaked CBR tests were conducted in accordance with the Nigerian General Specification (1997) which stipulates that specimens be cured dry for six days, then soaked for 24 hours before testing. The CBR compaction involved the use of the same rammer weight and drop height with each layer receiving 62 blows in a 2360 cm^3 CBR mould.

The WAS compacted carried out using energies derived from a rammer of 4.5 kg mass falling through a height of 45 cm in a 1000 cm^3 mould. The soil was compacted in five layers, each layer receiving 10 blows. For the CBR compacted the same rammer weight and drop height with each layer receiving 30 blows in a CBR mould. Finally, the BSH compaction moisture density relationships were determined using energy derived from a hammer of 4.5kg mass falling through a height of 45cm in a 1000cm^3 mould. The soil was compacted in 5 layers, each receiving 27 blows. The CBR compaction involved the same hammer weight and drop height with each layer receiving 62 blows in a CBR mould.

3.2.3 *Unconfined Compression*

Dried foundry sand – cement kiln dust mixtures were compacted at optimum moisture content using the three 3-compactive efforts of BSL, WAS and BSH. Tests specimen are of specified height to diameter ratio of 2.1 in accordance with BS 1377. The cylindrical specimens used in this test are of diameter 38.1mm and height 76.2mm. After compaction, the treated foundry sand was extruded from the mold and sealed with double wrappings in polythene bags that were kept in the humidity room at a constant temperature of 25 ± 2^{o}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.

3.2.4 *Durability*

The durability assessment of the soil stabilized specimens was carried out by immersion in water test for the measurement of resistance to loss in strength rather than the wet-dry and freeze-thaw tests highlighted in ASTM (Annual 1992), that are not very effective under tropical conditions. 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.

Table 1: Physical properties of foundry sand and CKD treated foundry sand

Engineering Properties	**Cement kiln dust (%)**			
	0	**4**	**8**	**12**
Liquid Limit, %	19.0	19.0	19.0	12.0
Plastic Limit, %	N.P.	N.P	N.P	N.P
Plasticity Index, %	N.P.	N.P.	N.P.	N.P.
Linear Shrinkage, %	0.9	0.8	0.9	0.8
Percent of fines	31	31	34	38
AASHTO Classification	A-2-4(0)	A-2-4(0)	A-2-4(0)	A-4(0)
USCS Classification	SM	SM	SM	SM
Specific Gravity	2.64	2.67	2.69	2.72
Color	Brown			
Dominant Clay mineral	Smectite			

Table 2: Oxide Composition of the Cement kiln dust

Oxide	CaO	Al_2O_3	SiO_2	Fe_2O_3	Mn_2O_3	Na_2O	K_2O	P^H	Gs
Concentration (%)	50.81	4.71	-	1.92	0.002	0.001	1.35	11.2	1.90

Source: Liman, 2009

4. *Results and Discussion*

4.1 *Index Properties*

The index properties of the untreated and treated foundry sand are shown in Table 1. The non-plastic sand is classified as A-2-4(0) according to AASHTO classification system (AASHTO, 1986) and SC according to the Unified Soil Classification System (ASTM, 1992). The liquid limit (LL) showed little variation in value from 19 to 12%. A decline in liquid limit value was observed at 12% CKD content. This decrease can be associated with the agglomeration and flocculation of the clay particles which is as a result of exchange ions at the surface of the clay particles.

Plasticity index values varied in the same pattern with the liquid limit. The addition of CKD to foundry sand did not have any significant change in the linear shrinkage this can be expected as the soil in question already posses' significant amount of fine sand which has no expansive or swelling tendency.

4.2 *Compaction Characteristics*

4.2.1 *Maximum dry density*

The variation of maximum dry density (MDD) for soil-CKD mixes are shown in Figure 1. The BSL, WAS and BSH compactive effort generally showed a decrease in MDD with higher CKD content, which is in agreement with Yoder and Witzack (1975). They reported that cement also decreases the density of soils and the same result can be expected of cement kiln dust since it is a waste generated from the production of cement. Furthermore, there is a possibility that the decrease in MDD is as a result of CKD which has a low specific gravity (1.90) replacing the soil particles which has a higher specific gravity of 2.64 as reported by Ola, (1978), Osula (1984) and Osinubi and Moses (2012) .

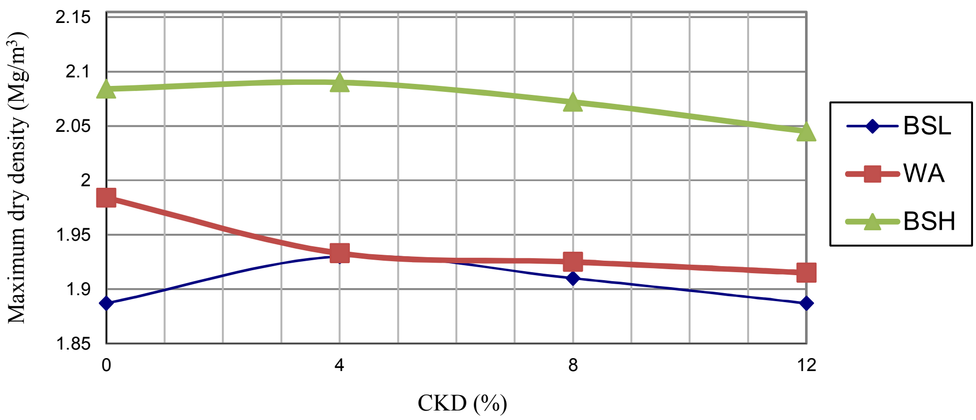

Fig.1: Variation Maximum Dry Density for CKD treated foundry sand mixtures

4.2.2 *Optimum Moisture Content*

The variation of OMC with for BSL, WAS and BSH compaction are shown in Figur 2. There was generally an increase in OMC with higher CKD contents for the West African standard and British standard heavy compactive efforts. It also could be due to the larger amounts of water required for the hydration of CKD. These results are in agreement with those reported by Nicholson and Kashyap (1993).

The decrease in OMC observed for specimens compacted at the BSL compactive efforts was probably due to self – desiccation in which all the water was used, resulting in low hydration. When no water movement to or from CKD – paste was permitted, the water is used up in the hydration reaction, until too little is left to saturate the solid surfaces and hence the relative humidity within the paste decreases. The process described above might have affected the reaction mechanism of the CKD treated specimen (Osinubi, 2000).

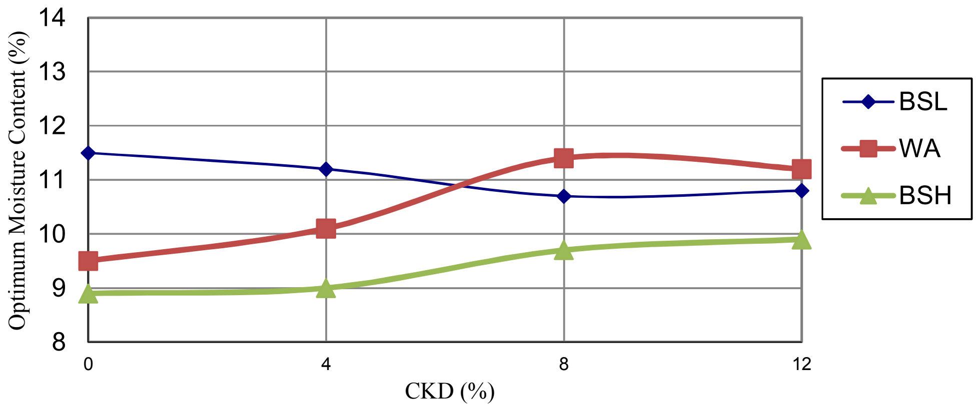

Fig.2 Variation of optimum moisture content for CKD treated foundry sand mixtures

4.3 *Unconfined Compressive Strength*

The unconfined compressive strength (UCS) test is recommended for use for determining the required amount of additive to be used in the stabilization of soils (Singh, 1991). The 7day UCS test results (see Figure 3) show peak values for BSL, WAS and BSH energy levels as 316 , 378 and 444 kN/m^2 at 12%, 8% and 8 % CKD treatments, respectively. The trend of the UCS for the WAS and BSH compactive energy level shows a marked difference from those of BSL compaction energies probably because of inadequate amount of water available for the pozzolanic reaction to take place at higher CKD treatments for higher energy levels (Osinubi and Moses, 2011, Osinubi et al., 2008, 2009). The peak value of CKD treated foundry sand was attained at 8% CKD content at BSL compactive effort with a peak 7 day UCS value of 444 kN/m^2. This value falls short of 1710 kN/m^2 specified by TRRL (1977) for base materials stabilization using CKD and fails to meet the requirement of 687–1373 kN/m^2 for sub-base as specified by Ingles and Metcalf (1972).

The variation of UCS with CKD at different CKD contents for 14 and 28 days curing period are shown in Figure 4-5. The peak 14 day UCS values for BSL, WAS and BSH compactive efforts are 554, 527 and 444 kN/m^2 at 12, 8 and 8 % CKD contents treatments, respectively. The peak 28 day UCS values for BSL, WAS and BSH compactive efforts are 690, 649 and 636 kN/m^2 at 12, 8% and 8% CKD contents treatments, respectively. This conforms to the trend of increasing strength with higher compaction energy as reported by Eberemu (2008) and Oriola and Moses (2011).

The gain in strength of specimens with age was due primarily to the long-term hydration reaction that resulted in the formation of cementitious compounds. The increase in UCS values could be attributed to ion exchange at the surface of clay particles. The Ca^{2+} in the additives (see Table.1) reacted with the lower valence metallic ions in the foundry sand microstructure which resulted in agglomeration and flocculation of the particles. The low UCS values at higher compactive effort can be attributed to insufficient water to complete the hydration reaction at higher compactive efforts (Osinubi and Stephen, 2007 and Osinubi and Moses, 2011).

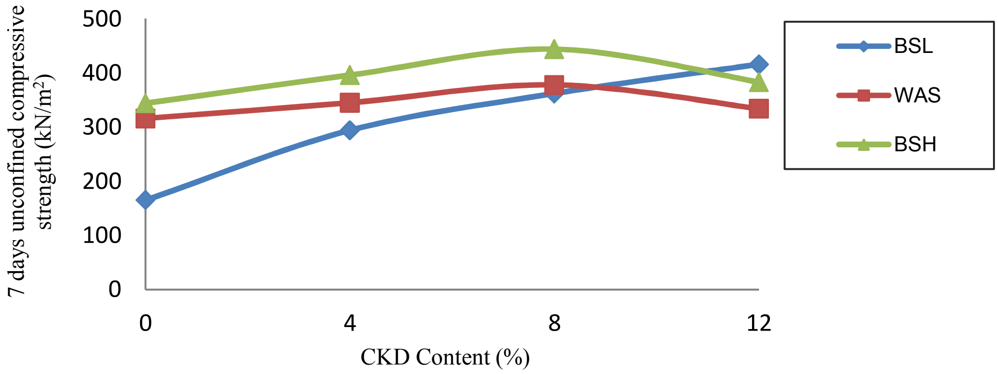

Fig.3: Variation of of unconfined compressive strength (7 days curing) for CKD treated foundry sand mixtures

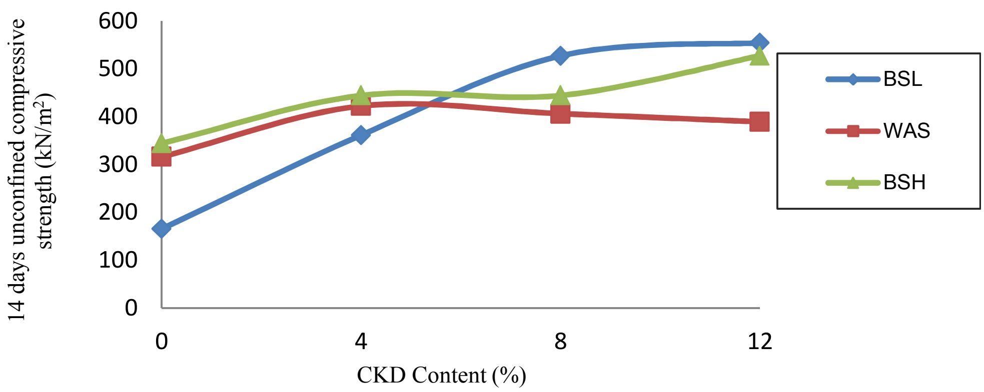

Fig.4: Variation of of unconfined compressive strength (14 days curing) for CKD treated foundry sand mixtures

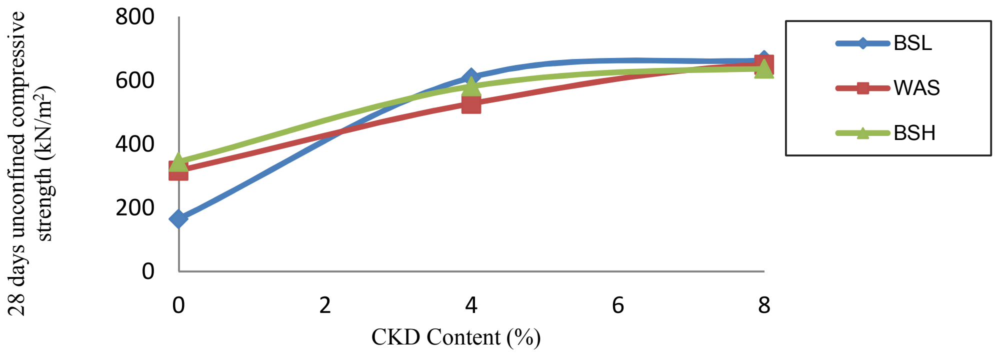

Fig.5: Variation of of unconfined compressive strength (28 days curing) for CKD treated foundry sand mixtures

4.4 *California Bearing Ratio*

The California bearing ratio (CBR) value, of the stabilized soils is an important parameter in assessing its suitability for use as a road construction material. It gives an indication of the strength and bearing ability of the soil; which will assist the designer in recommending or rejecting the soil as suitable for base or sub-base for a flexible road pavement.

The soaked CBR values (see Figure 6) gave peak values of 52, 20 and 15 % at treatment level of 12% CKD for BSH, WAS and BSL compactive effort respectively. These results followed the regular trend of increasing C.B.R. values with higher compactive effort similar trend were observed by Osinubi (2006). The reason for the improvement in the strength from 8% for the untreated foundry sand to 52% at 12% CKD treatment at BSH compactive effort could be due to the presence of adequate amounts of calcium (see Table.1) required for the formation of calcium silicate hydrate (CSH), which is the major compound for strength gain Osinubi (2000). Gidgasu and Dogbey, (1980) recommended a minimum CBR OF 60-80% for bases and 20-30% both when compacted at optimum moisture content and 100% West African standards. The peak CBR values obtained at 12% CKD treatment indicate that WAS and BSH compactive effort met the minimum value specified for sub-base material. The large variation in CBR value especially at 12% CKD for BSH compactive effort can be attributed to the higher energy level which leads to densification of the particles with resultant increase in strength value.

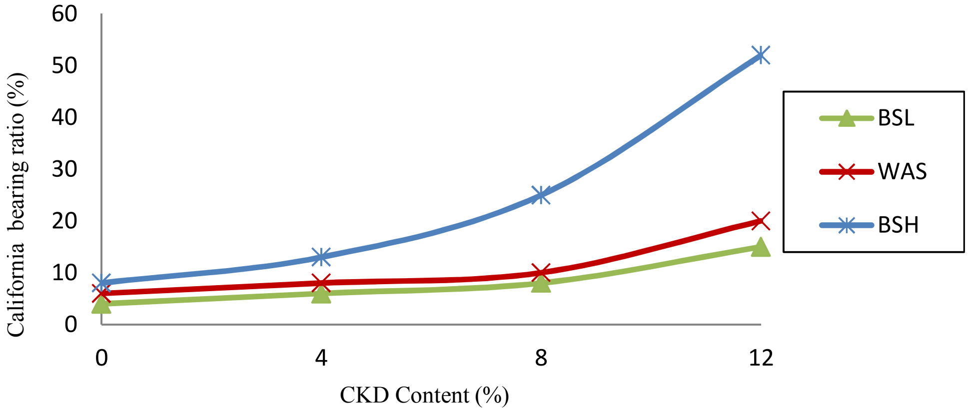

Fig.6: Variation of california bearing (soaked) ratio for CKD treated foundry sand mixtures

4.5 *Durability Assessment of Specimens*

In order to simulate some of the worst conditions that can be attained in the field for any soil to be used for engineering purposes, immersion of the cured specimen in water before testing its compressive strength is employed to ensure that the stabilized material do not fail under adverse field conditions. The UCS values obtained under these conditions are analyzed in conjunction with the 14 days curing period UCS test results. Specimens are normally cured for 7 days before immersion in water for another 7 days before testing to obtain the percentage resistance to loss in strength of the stabilized material as recommended for tropical countries by Ola (1974).

The loss in strength values for BSL, WAS and BSH compactive energy levels is shown in Figure 7. The peak loss in strength value of 73.4 at 0% CKD content for BSL, 67.0 at 8% CKD content for WAS and 73.3% at 8% CKD content for BSH compactive efforts, respectively. All tested specimens fell short of the maximum 20% allowable loss in strength reported by (Ola, 1974). However, the loss of strength limiting value obtained Ola (1974) was based on a 4 day soaking period and not the 7 days soaking period that the specimens were subjected to in this work. However, because of the harsher 7 days immersion period used in this study and the expected long-term gain in strength the mixtures, improvement in the durability value is expected.

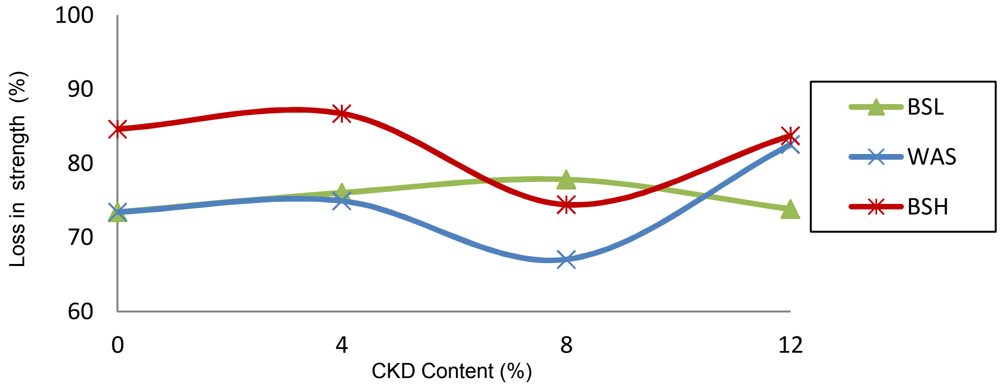

Fig.7: Variation of loss in strength for CKD treated foundry sand mixtures

Conclusion

The untreated foundry sand was classified as A–2-4(0) or SM in the AASHTO and Unified Soil Classification System (USCS), respectively. Soils under these groups are of poor engineering benefit. The variation of maximum dry density (MDD) for soil-CKD mixes for BSL, WAS and BSH compactive effort generally showed a decrease in MDD with higher CKD content. There was generally an increase in OMC with higher CKD contents for the West African standard and British standard heavy compactive efforts. It also could be due to the larger amounts of water required for the hydration of CKD.

The decrease in OMC observed for specimens compacted at the BSL compactive efforts was probably due to self – desiccation in which all the water was used, resulting in low hydration. When no water movement to or from CKD – paste was permitted, the water is used up in the hydration reaction, until too little is left to saturate the solid surfaces and hence the relative humidity within the paste decreases. The process described above might have affected the reaction mechanism of the CKD treated specimen.

The peak CBR values of 20 and 52% at treatment level of 12% CKD for WAS and BSH compactive effort satisfy the recommended minimum for sub-base material. The durability assessment of the specimen failed to produce an acceptable result based on the loss in strength test carried out. Generally, the BSH compactive effort produced the best result which is in conformity to previous research work.

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