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Effects of Steel Mill Dust on the Strength Characteristics of Black Cotton Clay Soils

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Abstract— the results of laboratory investigations on the influence of steel mill dust on the strength characteristics of tropical black cotton clay soils are presented. Tropical Black Cotton clay soils were mixed with steel mill dust at 5%, 10%, 15%, 20%and 30% steel mill dust content (by dry weight of soil) in order to establish the soil stabilizing potentials. The Unconfined compressive strength and CBR tests on the soil-steel mill dust mixtures yielded peak values at 30% mill scale content. The soil-steel mill dust mixture can be used as subgrade and sub-base courses of rural roads when compacted at the energy of the West Africa Standard.

Index Terms— Black cotton clay soil, Steel mill dust, Strength Characteristics.

1 Introduction

BLACK cotton soils (BCS) are dark coloured expansive clays found in North-East Nigeria and other parts of the world including India, USA and Canada (ASCE [2]; Sabat [19]; Osinubi et al [13];). They are characterized by the presence of montmorillonite in the mineralogy, which is capable of absorbing large volumes of water due to its structure (Shamrani et al [21]; Osinubi [16]; Ola [11]). Black cotton soils present various challenges to engineers all over the world due to its characteristic of severe loss of strength and swelling with respect to changes in moisture regime. As a result, structures, roads and highways constructed on black cotton soils are subject to severe deformations and frequent repairs leading to high cost of maintenance. Various efforts are being made to stabilize black cotton soil with cement, lime, admixtures and waste products to make them meet requirements for construction works (Osinubi et al [13]; Ola [12], Balogun [4,5]), but the cost of incorporating the additives is high while cracks develop with cement.

Hence researches have focused on potentially cost effective materials that can improve the properties of black cotton soil, Osinubi [16]. Series of studies on the improvement of tropical black cotton clay soils using processed industrial and agricultural wastes as additives are being conducted, Osinubi [14], [15], [16]. Physical and chemical alteration of expansive soils using solid wastes like fly ash, rice husk ash, marble dust, phosphogypsum, granulated blast furnace slag, red mud, waste tyre etc are ways of utilizing wastes, (Sabat [19]; Sabat and Nanda [20]; Patil et al [17]). Steel mill dust (SMD) is a metal industry waste which is produced in large tons during casting, hot rolling and reheating of steel.

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Steel Steel mill dust poses grave disposal problems; therefore Steel mill dust poses grave disposal problems; therefore the use of steel mill dust in soil stabilization is of much economic and environmental benefit.

1.1 Location and Geology of the study area

Disturbed soil samples used for this investigation were collected along the Dikwa-Gamboru Road, Borno State, Nigeria. It is part of the area extensively covered by the Black Cotton Soil of North-Eastern Nigeria. The study area falls within the Chad Basin which is part of the lacustrine and fluviatile clays and sands of the Pleistocene age laid down during the late Tertiary and Quaternary periods, Ola [12].

2 Materials and methods

2.1.1 Tropical Black Cotton Clay Soil

Tropical black cotton clay soils were collected along the Dikwa-Gamboru Rd, Borno State, Nigeria. The soils used in the study are dark grey clay soil classified as A-7-6 in the AASHTO Soil Classification System, AASHTO [1] and CL in the United Soil Classification System, ASTM [3]

2.1.2 Mill Scale

The steel mill dust, an industrial waste, was collected from a Steel manufacturing company in Ikeja, Lagos state, Nigeria. The steel mill dust was pulverised into finer particles and added in varying proportion by weight (5%, 10%, 15%, 20% and 30%) to the soil samples.

2.2 Soil Index Properties

Fresh soil samples collected and tested within 3 months were used in order to prevent alteration of the properties of the residual soil. All the samples were air-dried for 1-day before testing in order to simulate field conditions as suggested by Peck [18]. X-ray diffraction (XRD) analysis was carried out on the soil samples to aid the identification of the clay mineral present. The predominant clay mineral present in the soil samples was found to be montmorillonite. The results are in agreement with those obtained by Ola [12] and Osinubi [16] for soils from the study area. A summary of the soil index

properties is presented in Table 1. A summary of the oxide and metallic composition of the clay soil and mill scale is presented in Tables 2 and 3
Laboratory tests were performed on the samples in accordance with British Standard, BS 1377 [6] for the natural soil and BS 1924 [7] for the treated soil. California Bearing ratio (CBR) tests were done in accordance with the Nigerian General Specifications [9] which stipulates that specimens are to be cured in the dry for 6 days and then soaked for 24 hours before testing. The soil was characterized and classified by the following tests: Atterberg limits, compaction, California bearing ratio (CBR) and unconfined compressive strength (UCS).

2.3 Compaction Tests

Tests involving the compaction tests and strength tests of CBR and Unconfined compressive strength were carried out using the West African Standard (WAS) energy levels. If the BS (Proctor) compaction mould is used, the compactive effort for the WAS consists of the energy derived from a 4.5kg rammer falling through 45cm onto five layers, each receiving 10 blows. When the CBR mould is used, the WAS compactive effort is also derived from a 4.5kg receiving 25 blows (Osinubi 1998a, b). WAS compaction is commonly used in West Africa region.

3 Results and Discussions

3.1 Mineral Composition

The result of the chemical analysis is presented in Tables 1 and 2. The main oxides present in the soil sample and the steel mill dust are Silicon Oxide (S_IO_2) and Aluminium Oxide (Al_2O_3). Steel mill dust has a much higher Silicon Oxide component. Iron Oxide and Calcium Oxide are very low. Ferric Oxide is the main component of lateritic soils. The main metals present in the soil samples are Copper, Manganese and Iron, Table 2.

Table 1: Oxide Composition of Samples

Mineral (%)	Soil sample	Steel mill dust (SMD)
S_IO_2	39.61	62.3
Al_2O_3	30.87	20.3
Fe_2O_3	0.43	3.3
CaO	0.39	1.2
MgO	0.36	0.44
Na_2O	0.09	0.03
K_2O	0.52	0.01
SO_3	0.13	0.03

Table 2: Metallic Composition of Samples

Mineral (Kg)	Soil sample	Steel mill dust
Cadmium	Not detected	Not Detected
Copper	3.13	0.16
Manganese	1.35	2.41
Nickel, Nl	0.04	0.05
Lead, Pb	Not detected	0.04
Iron, Fe	2.34	3.14
Zinc, Zn	0.70	3.0

3.2 Index Property of Soils

The Index properties of the soil sample are summarised in Table 3. Classification test indicates that the underlying soil lies above the A-line (Fig.3) and can be classified as A-7-6 soil under the AASHTO Soil Classification System [1] or CH in the United Soil Classification System. The soil is clayey.

Table 3: Index properties of soil sample

Property	Soil sample
Liquid limit, %	66.0
Plastic limit, %	24.5
Plasticity Index, %	41.5
Shrinkage limit, %	9.4
Free Swell, %	70
Optimum moisture content, %	20.5
Maximum Dry Density, MDD (Mg/m^3)	1.484
Unsoaked CBR (%)	24
Soaked CBR (%)	15
UCS	32.7
Swell potential	High
Free Swell	High
Compressibility	High

3.3 Effect of Steel mill dust on Compaction Characteristics

The effect of steel mill dust content on the maximum dry density (MDD) and the optimum moisture content (OMC) of the soil-steel mill dust mixture for the West Africa Standard compactive efforts, WAS, are shown in Figs.1, 2 and 3 respectively. The MDD of the steel mill dust stabilized soil increased with increase in steel mill dust content while the OMC reduced with increase in steel mill dust content. The results show that the steel mill dust increased the compaction and strength of the soil while reducing the moisture content. Lime usually reduces the MDD and increases the OMC of clayey soils at a given compactive effort; Osinubi (2006), the trend observed here is therefore opposite that of the established effect of lime. The steel mill dust increased the MDD of the soil by 28% from $1639kg/m^3$ to $2094kg/m^3$ at 30% steel mill dust content. The MDD obtained at 15% steel mill dust content and above is within the range of 1720 to $1920kg/m^3$ which is considered satisfactory to excellent. The strength obtained at 15% steel mill dust content appears to tally with the findings of Murthy [8]. The OMC of the soil sample was reduced by about 45%. The reduction in OMC can be attributed to the reaction between the clay particles and the positively charged metals in the steel mill dut.

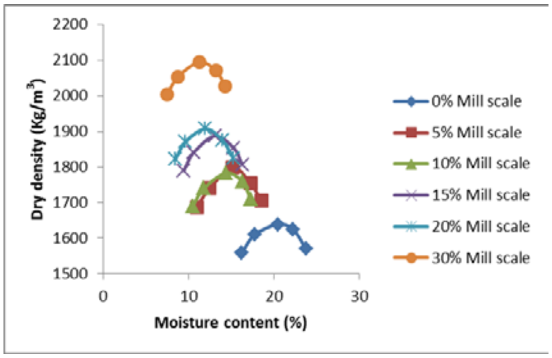

Fig.1 Moisture-Dry density relationship with varying Steel Mill Dust content for the soil-steel mill dust mixture

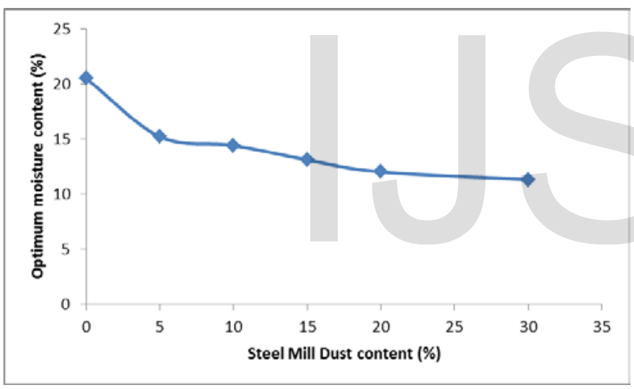

Fig.2 Variation of Optimum moisture content with varying Steel Mill Dust content for the soil-steel mill dust mixture

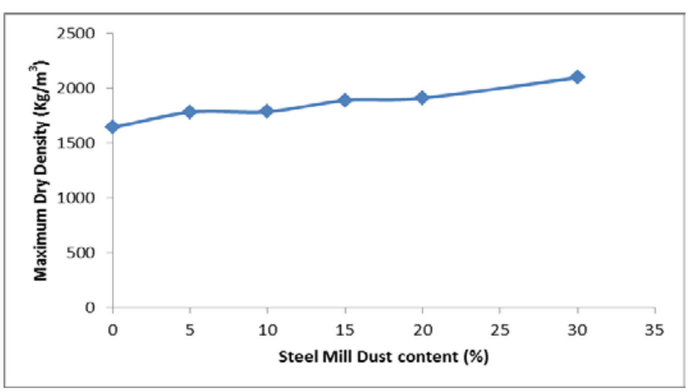

Fig.3 Variation of Maximum dry density with Steel Mill Dust for the soil-steel mill dust mixture

3.4 Effect on Strength Characteristics

3.4.1 California Bearing Ratio

The CBR test results shown in Fig.4, Fig.5 and Fig.6 show two trends. Fig.4 indicates that although the natural soil has low CBR values, there is appreciable increase in strength with the addition of steel mill dust to stabilize the tropical black clay soil. The figure further reveals that Unsoaked CBR increases with increase in steel mill dust content. The Un-soaked CBR increased by up to 50% at steel mill dust content of 30% with no tendency to reduce. A peak Un-soaked CBR value of 58.8% was obtained using the WAS compaction. This is above the minimum conventional CBR value of 40% required for subbase (lightly trafficked roads). Fig.5 shows that the Soaked CBR decreases with increase in steel mill dust content. The soaked CBR of the natural soil was greatly reduced by the steel mill dust thereby indicating a significant disintegration of the stabilised mixture in the presence of water. However, if the mixture is protected from water, the Un-soaked CBR of the steel mill dust stabilised soil is above the minimum CBR requirement of 40% for subbase. The addition of cement or lime to the steel mill dust stabilized soil may prevent the loss of strength in the Soaked CBR. This is a subject of further investigation. Fig.6 shows that the swelling potential reduced with increase in the steel mill dust content which is a positive sign for this high swell clay soil.

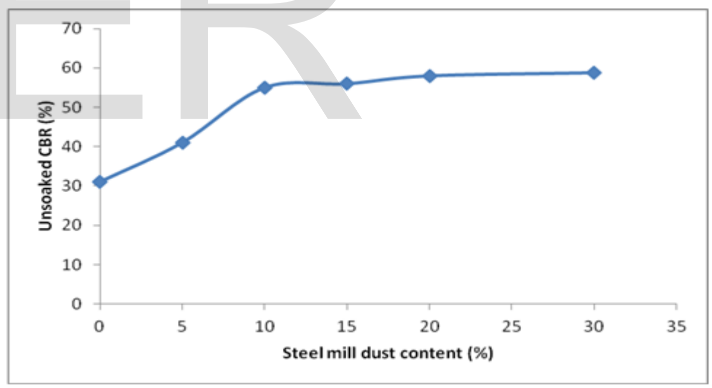

Fig.4 Variation of Un-soaked CBR with Steel Mill Dust content for the soil-steel mill dust mixture

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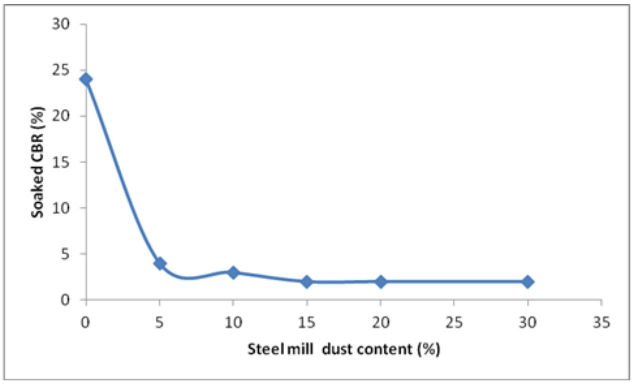

Fig.5 Variation of Soaked CBR with Steel Mill Dust content for the soil-steel mill dust mixture

Fig.7 Variation of Unconfined Compressive Strength with Steel Mill Dust content for the soil-steel mill dust mixture

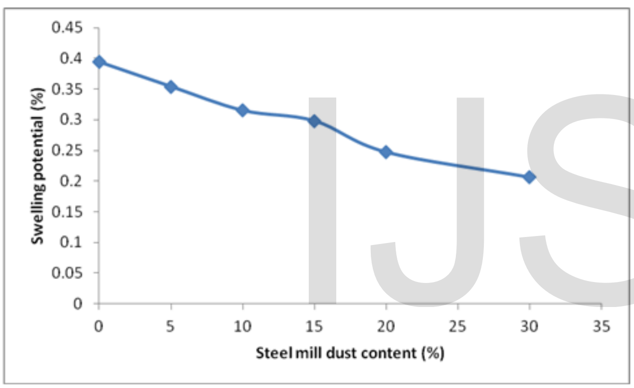

Fig.6 Variation of Swelling potential with Steel Mill Dust content for the soil-steel mill dust mixture

3.4.2 Effect on Unconfined Compressive Strength

The variation of UCS with steel mill dust content for the stabilized soil-steel mill dust mixture is shown in Figs.7. The addition of steel mill dust to the tropical black cotton soil weakened the soil by reducing the UCS of natural soil from about 30KN/m^2 to about 12KN/m^2. The results obtained show that specimens treated with steel mill dust alone do not meet the minimum UCS required. Hence the need for further investigations.

CONCLUSSIONS

From the tests and results obtained, the following conclusions can be drawn:

i. The addition of steel mill dust increased the Maximum Dry Density, MDD, of tropical black cotton soil by about 28%. The MDD increased from 1639Kg/m^3 t0 2094Kg/m^3 which is considered satisfactory to excellent.

ii. The Optimum Moisture Content, OMC, of the tropical black cotton soil was lowered by about 45% by the addition of steel mill dust.

iii. The addition of steel mill dust increased the Un-soaked CBR of the tropical black cotton soil by about 90% at 30% steel mill dust content. A peak un-soaked CBR value of 58.8% was obtained using the WAS compactive effort which is above the minimum CBR value of 40% required for subbase of lightly trafficked roads.

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