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Evaluation of Performance of Quarry Dust as Additive for Stabilizing Black Cotton Soils

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ABSTRACT

This paper presents a laboratory investigation into the efficacy of quarry dust as an additive for enhancing the strength characteristics of black cotton soil. Based on the AASHTO classification system and the USCS, the studied soil belongs to A-7-6(12) and CH respectively, implying that the soil is unfit for engineering purposes. The modification of the soil was carried out by treating the soil with 0-30% by weight of quarry dust in 5% increments. Results of compaction tests on the modified soil indicated that, the maximum dry density increases from 1.7 to 1.92 Mg/m^3 as the modifier is varied from 0-20%. Conversely, the optimum moisture content decreases from 16 - 7.1% for the same variation of the modifier. The CBR value also increases as the amount of quarry dust is increased (from 9 when untreated to 19% when treated with 20% of additive), thus indicating that the additive has the tendency to enhance the strength characteristics of the expansive soil. Based on CBR criterion, the recommended percentage of modifier is 15, being the smallest quantity of quarry dust that satisfies the criteria for a suitable sub-grade cover.

Keywords: Black Cotton Soils; Soil Stabilization; Quarry Dust

INTRODUCTION

Black cotton soils (BCS) are dark grey-coloured highly expansive clays found in many parts of the world including North-East Nigeria. This type of soil tends to undergo large volumetric changes coupled with huge variations in strength and stiffness due to fluctuations in the moisture content. Swelling and shrinkage cycles undergone by untreated black cotton soils due to seasonal variations could result in millions of Naira worth of damages to foundations, road pavements, retaining walls and the like. This erratic behaviour makes such type of soil unsuitable for engineering purposes and has to undergo one soil improvement method or another for it to be used as construction material or supporting medium.

Quarry dust is a waste material that could be used as an additive for the sake of achieving a cost-effective ground improvement of marginal soils such as black cotton clays. The quarry dust is obtained at quarries during the processing of stones to obtain aggregates. About 20-25% of the total production for a typical crusher comes out as waste in quarries. Considering the volume generated waste, quarry dust is in such a supply that makes its use as a modifier a sustainable and viable one.

In this research, a geotechnical investigation is undertaken to study the effectiveness of quarry waste in enhancing the strength characteristics of black cotton soils. The idea is in line with the effort to minimize the cost of ground improvement, reduce carbon foot-print and manage wastes more effectively in the construction sector.

Previous Related Works

From the literature, numerous studies on the use of quarry dust for soil improvement have been undertaken. Ali and Korrane, (2011) studied the effect of stone dust and fly ash on characteristics of expansive soil. They concluded that there is a marked improvement in the strength and index properties of

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expansive soil if stone dust and fly ash are mixed in equal proportions. Mudgal *et al*., (2014) studied the effect of stone dust on lime stabilized BCS and made similar findings as in Ali and Karonne, (2011). Other researchers such as Akanbi *et al.*,(2014), and Sudhakar *et al*., (2021) studied the effect of stone dust on expansive soils and concluded that the waste has a significant and positive effect on the properties of the marginal soils. More recently, Sajad, S. and Singh, H. (2022) and Tsige *et al*., (2023) conducted experimental investigations on the role of granular wastes (stone dust and sandcrete waste) as co-additives for black cotton soil stabilization. In both studies, the granular wastes, jointly with other additives, significantly enhanced the strength of the modified soils. The present work aims to find out if similar success can be achieved by treating the BCS in Numan Local Government Area in Adamawa State.

MATERIALS AND METHODS

Soil

The soil used for this research is Black cotton soil and was obtained by disturbed sampling from a location around Dangote Sugar Company in Numan LGA, Adamawa State of Nigeria. The soil samples were collected at depths between 1.0 and 1.5 m. The samples were collected and sealed airtight in polythene bags and transported to the laboratory for investigation.

Figure 1: Black Cotton Soil

Quarry Dust

The quarry dust used in this research was obtained from Dawakin Kudu Kano State H&M Quarry site. Only the fraction passing through BS sieve No. 4 (4.76mm) was used in the study.

Figure 2: Quarry Dust

Laboratory Tests

In order to prepare the black cotton soil samples for laboratory procedures, the collected soil lumps were air-dried and pulverized to obtain particles passing 425 µm sieve. The following laboratory tests were conducted on the natural soil sample in accordance with the British Standard method of soil testing for Civil Engineering purposes (BS1377):

A. Sieve analysis: This test is meant to evaluate the distribution of soil grain sizes, which constitute the soil fabric. It is also used in soil classification and as a basis for some aspects of geotechnical design judgements.

B. Plasticity tests: This is used to evaluate the plastic behaviour of the fine fraction of the soil. The parameters determined in this series of tests include the liquid and plastic limits, and linear shrinkage.

C. Specific gravity test: The particle specific gravity of the samples was determined using pycnometer method. This is a very useful physical parameter that serves as input in quite a number of geotechnical design calculations.

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D. Compaction test: This is meant to determine the maximum density and the corresponding moisture content. In this study standard proctor method of compaction is adopted

E. California Bearing Ratio (CBR) test: This test is meant to provide insight into the strength and stiffness of the soil.

To examine the stabilizing efficacy of the additive, various proportions of the quarry dust - soil mixture were subjected to CBR and compaction tests Soil mixtures were prepared by combining dry Black cotton clay with quarry dust in proportions of 0%, 5%, 10%, 15%, and 20% by weight of dry soil.

RESULTS AND DISCUSSION

Particle Size Distribution and Index Properties

Particle size analysis of the natural soil (see Table 1) revealed that, the fine content (silt and clay) is 79% which implies that the soil is Fine (either clay or silt). Table 2 shows the general properties of the soil with Liquid Limits (LL) of 78%, Plastic Limit (PL) of 33% and Plasticity Index (PI) of 45% which also exceeded the threshold values for materials suited for pavement sub-base and base. The co-ordinate of the soil in the plasticity chart indicated the soil is above the A-line and is therefore regarded as Clay.

Table 1: Distribution of particle sizes in the sampled black cotton soil

Gravel =	0.00%	
Coarse Sand =	4.50%	Sand
Medium Sand =	8.40%	21.00%
Fine Sand =	8.10%	
Fines =	79.00%	

Based on the particle gradation and consistency limits, the American Association of State Highway and Transportation Officials (AASHTO) classification of the soil is A-7-6 and also classified as CH in the United Soil Classification System, thus requiring improvement to suit the design requirements for flexible pavement or subgrade cover.

Also, from the results summary in Table 2, it can be noted that the natural soil has a very highvalue of linear shrinkage, implying a strong swelling-shrinkage potential. Although the relationship between the former and the latter is complicated, nevertheless, the two are strongly (and positively) correlated. This large value is indicative of the erratic patterns of volume change and extremely large soil displacements observed in this type of soil.

Compaction Characteristics and the Effect of Quarry Dust

Figure 4 shows the variation of OMC and MDD with increasing quarry dust content. As can be seen, the higher the quarry dust content,

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the greater the degree of compaction. MDD increased from 1.73 to 1.92 Mg/m^3 as the quarry dust content varies from 0 to 20%. Correspondingly, the OMC declines from 13.4 to 7.1 % over the same range of quarry dust increase. Such a decrease in the optimum moisture content means that the dust tends to reduce the impact of high plasticity and swelling characteristics of BCS on compaction efficiency. The sustained increase in MDD implies that with the addition of quarry dust, the deformability of the soil tends to decrease with an increase in dust content, the reason being that, generally, higher dry densities correspond to greater stiffness.

Table 2: Properties of the Black Cotton soil

Parameter	Value
Liquid limit (%)	78
Plastic limit (%)	33
Plasticity index (%)	45
Specific gravity	2.68
Linear shrinkage (%)	89.29
Maximum dry density(Mg/m^3)	1.73
Optimum moisture content (%)	13.4
California bearing ratio % (Unsoaked)	9.02

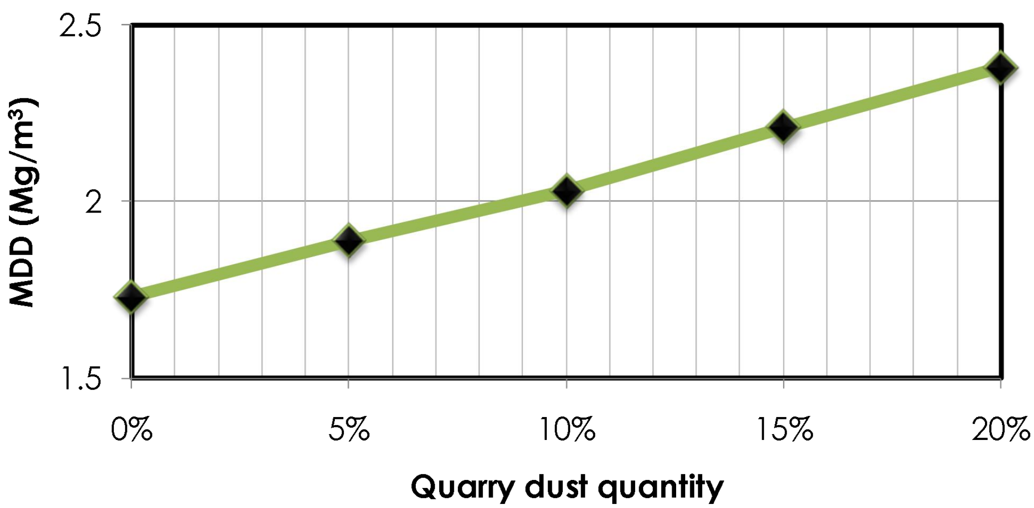

Figure 3: Variation of Maximum Dry Density (MDD) with quarry dust content

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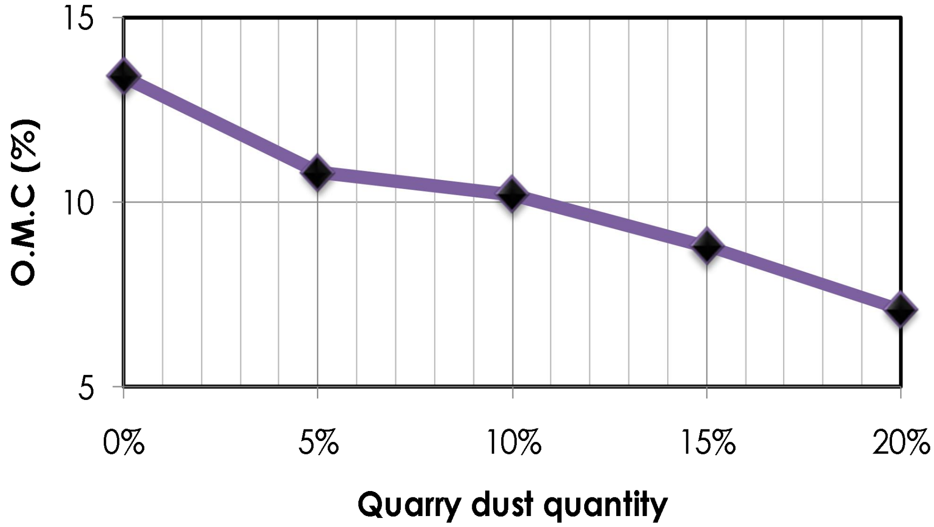

Figure 4: Variation of Optimum moisture Content (OMC) with quarry dust content

California Bearing Ratio (CBR) and the Effect of Quarry Dust

The CBR is one of the measures of soil strength and has been widely regarded as a basis for pavement design. Results of CBR tests carried out on treated and untreated samples are presented in Figure 5, which shows that the values of CBR consistently increase as the quarry dust content increases. It is also noteworthy that, the unsoaked CBR value of untreated black cotton clay belongs to S3 class in accordance with the Federal Ministry Works Pavement Design guideline (2013), which is a low-strength subgrade. For the treated soil with treated with 5% and 10%, the CBR appreciates but not up to the 15 % threshold for a suitable subgrade cover. It seems from the CBR-versus-quarry content chart that the soil needs to be treated with a quarry dust quantity of 14% or more for it to satisfy the minimum requirement of 15% for subgrade cover.

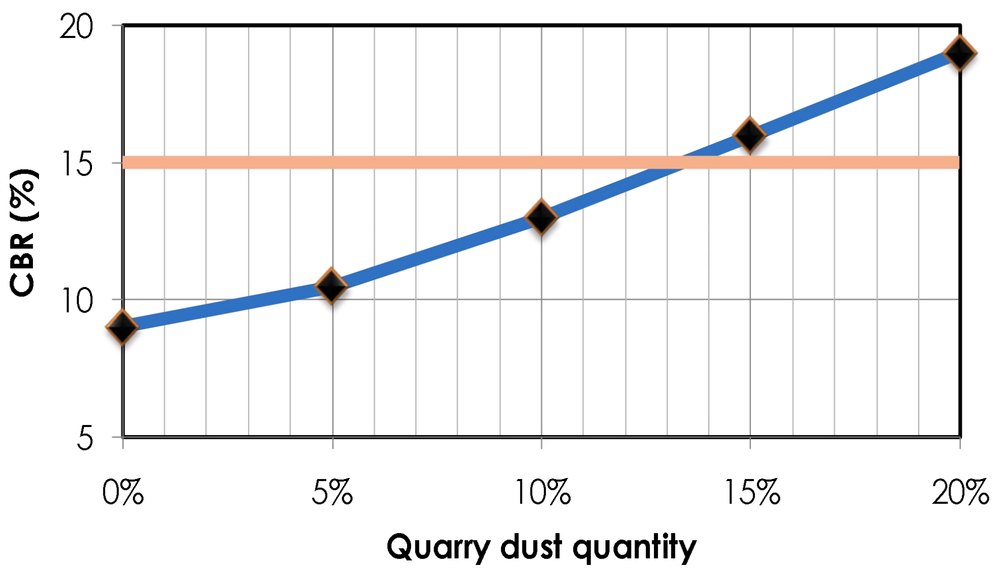

Figure 5: Variation of California Bearing Ratio (CBR) with Quarry Dust Content

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CONCLUSION

This research investigated the effect of treating black cotton soils with the residue of stone chippings production, otherwise known as quarry dust. Based on the result obtained in the course of the study, the following conclusions are drawn:

1. The natural Black Cotton soil was classified as A – 7 – 6 or CH in the AASHTO and Unified Soil Classification System (USCS), respectively. Soils under these groups are considered unsuitable for engineered constructions in their natural form. .

2. With the percentage by weight addition of Quarry dust content, the maximum dry density (MDD) of the tropical Black Cotton soil increased from 1.73 Mg/m^3 to 1.92 Mg/m^3 and the Optimum Moisture Content (OMC) decreased from 13.4% to 8.1%.

3. A positive correlation exists between the California Bearing Ratio (CBR) of the investigated soil and quarry dust content as the CBR consistently increases with the increase in the dust content.

4. For additive content below 14%, the treated soil remains within S3 subgrade class and is not suitable for use as subgrade cover. It is therefore recommended based on this study that at least 15% of additive is required for the treated soil to be suitable as subgrade cover,

Recommendation

Due to the limitations of stand-alone quarry dust in significantly improving the strength properties of black cotton soil, it is worthwhile to investigate the benefit of using a combination of quarry dust and pozzolanic additives such as rice husk ash. The ability of pozzolanas to chemically react with the clay minerals to reduce the swelling-shrinkage potential and enhance shear strength is likely going to give a significant boost to the overall performance (in terms of soil improvement) when combined with the quarry dust.

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