

Review Article

Assessment of the CBR and UCS Performances of Problematic Soil Improved with Lead-Zinc Mine Tailings and Cement using Taguchi Optimization Technique

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Abstract

Waste management and its sustainable use are essential to every country's development because they protect the environment and provide economic benefits. Open dumping and environmental hazards posed by mine wastes gave rise to this research, which seeks an alternative use for such wastes in the Civil Engineering field. The sustainable use of lead-zinc mine tailings (LZMT) on an expansive soil in the presence of Portland limestone cement (PLC) was examined in this work. The poor soil being expansive was mixed with varying amounts of LZMT and PLC. They were then evaluated for their impact on the expansive soil's compaction, California bearing ratio (CBR) and unconfined compressive strength (UCS) characteristics. According to the assessment's results, adding 20% LZMT and 12% PLC to the soil produced the best mix of LZMT and PLC for combined improved performance of the expansive soil's maximum dry density (MDD), CBR and UCS. This research adopted Taguchi optimization techniques to optimize the expansive soil stabilized with the lead-zinc mine tailings and cement for consideration in road sub-base and subgrade construction and the orthogonal array of Taguchi optimization technique was also used to develop the design experiment. Based on the Taguchi optimization technique, and the satisfaction of the Federal ministry of works of Nigeria, Highway design manual part 1 (2013) standard for road sub-base, a combined optimum mix of 20% lead – zinc mine tailing and 12% cement is recommended for use; while for subgrade, 15% lead – zinc mine tailing, 8% cement is recommended for use based on the same standard.

INTRODUCTION

Mine tailings are the tailings also known as waste which are derived from extracted mineral ore and appear as mud material in look and texture. Globally, environmental issue has been a major issue in the mining industry, and the most encountered issue is the storage mechanism. Toxicity exists amidst the different varieties of tailings and therefore needs to be stored away from the environment at all times. Due to the fact that metal extraction is typically a small proportion of each ton of ore, tailings generation is massive [1].

The size and nature of mine tailings are determined by the mining method. Tailings are a fine sludge or powder that remains after desirable minerals have been extracted from ore in hardrock metal mines, it will be important to characterize these ores in order to identify the specific minerals present in them and the order of concentration.

Tailings should not be confused with "waste rock," which is a rock that does not contain the desired ore and that miners excavate and dispose while digging for the underlying ore. They're also distinct from soil and organic material that's removed from the top above the ore deposit often referred to as overburden [2].

Problematic soils such as expansive soils are often interjected during certain Civil Engineering projects such as subgrade preparation, soil embankments, retaining walls backfills etc. in tropical environments [3,4]. Problematic soils are found to swell at the presence of water and shrink as water is expelled. A common expansive soil is black cotton soil, which was considered in this research, they exist in large quantity in the North – east axis of Nigeria. They exist in nature varying from dark grey to black in colour having clay content usually exceeding 50%, having montmorillonite as the predominant clay material [5,6].

Taguchi optimization technique is a system for analyzing and implementing changes in process parameters. It forms a robust system to achieve the desired target of a process with far fewer experimental designs. Taguchi technique considers orthogonal arrays instead of the traditional full factorial test designs which need all possible combinations to attain optimal performance of a system. Orthogonal array in Taguchi method produces an efficient design system.

This work involves the use of lead-zinc mine tailings to partially replace cement in the stabilization of problematic soil in the tropics and the CBR and UCS performance are to be investigated for use in subgrade and subbase layers of a road.

MATERIALS AND METHODS

The problematic soil considered is black cotton soil (BCS) which was obtained along Taraku - Naka - Agagbe road in Benue State, Nigeria (7° 37' 39" N, 8° 13' 34" E), about 5.37km away from Gwer West Local Government Secretariat, Benue State, Nigeria. This was done using a disturbed sampling method of sample collection at over 0.5m below the surface.

The lead-zinc mine tailing was obtained from First Patriot Ltd., a mineral ore mining company located at Enyigba, Ikwo, Ebonyi state. The lead-zinc mine tailing is a waste product derived after the extraction of lead and zinc from the mineral ore, it was obtained in a wet state and then to be air-dried at atmospheric conditions. The cement used is Portland limestone cement obtained from a cement supply store in Ebonyi state. Taguchi optimization technique was adopted to generate the mix proportions using the orthogonal array. LZMT was considered from 0% to 30% at 5% interval, while PLC was considered from 0% to 12% at 4% interval. A total of 18 mix proportions in addition to the natural soil sample were considered from the orthogonal array.

Preliminary tests and micro - analysis of the additives soil and additives were carried out in accordance to ASTM standard. Preliminary tests done include particle size distribution, specific gravity, Atterberg limits.

Compaction test, CBR test, and UCS test were carried out on the stabilized samples, while CBR test was done at both soaked and unsoaked states with both PLC and LZMT. All the laboratory tests were carried out at MDD and OMC and done in accordance with the ASTM standard. The optimum mixes were established to meet the requirements for subgrade and subbase layers of the road.

RESULTS AND DISCUSSIONS

The preliminary tests and natural soil tests results are shown in Table 1 below.

The admixing of the additives with the BCS tend to reduce further the percentage of the fines due to the flocculation and agglomeration of the mixtures thereby enabling the clay fraction to form increased soil particles [7,8]. According to Odumade (2018), sand size particles contribute to mechanical strength, whereas clay's colloidal component gives the required fluidity or workability. Based on the analysis of the particle size distribution of the soil with its computations, it was observed that all the soil samples passed through sieve 4.75 mm.

Also, it was observed that about 65% falls below 0.075mm; therefore, it can be concluded that the soil contains a high level of clay. The LZMT was observed to contain fines of about 50% passing through 0.075mm sieve, being more granular than the soil. The interaction of the tailing tends to reduce the fines in the conglomerate as the quantity of fines in the mine tailing is clearly far less than the black cotton soil as seen in Figure 1.

Table 1: Preliminary results of the natural soil

S/No	Property	Description	
1.	Specific gravity of BCS	2.29	
2.	Specific gravity of LZMT	2.86	
3.	Percentage Passing BS No. 200 Sieve (75 µm aperture)	64.8%	
4.	Natural moisture content %	23.4%	
5.	Liquid limit %	58.2%	
6.	Plastic limit %	29.8%	
7.	Plasticity index %	28.4%	
8.	MDD	1.57g/cm ³	
9.	OMC	21.78%	
10.	AASHTO classification	A-7-6(24)	
11.	CBR	Unsoaked	5.33%
		Soaked	2.15%
12.	UCS	98.07KN/m ²	

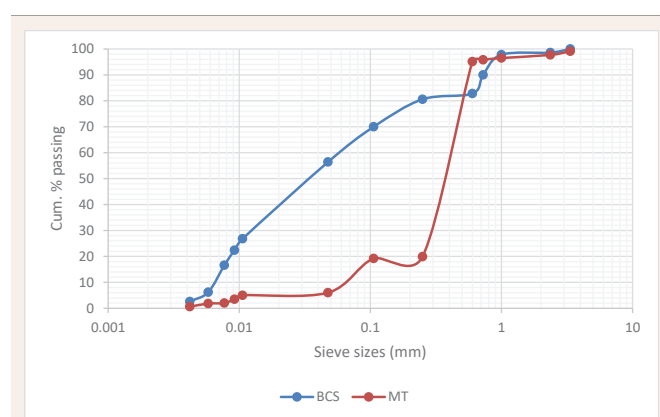


Figure 1 Particle size distribution comparison of BCS and LZMT

COMPACTION TEST RESULTS

From the compaction tests, analysis, and plot in Figure 2; the MDD for all the stabilized samples increased with an increase in cement content (PLC). The stabilized soil samples have the highest MDD at 12% cement (PLC) for each percentage of LZMT. The influence of LZMT additive was seen to have an increment in the MDD up to a point and reduced with further addition of LZMT.

The OMC from the analysis and plotting in Figure 3 was observed to decrease with cement content. 5% LZMT and 4% PLC gave the highest value of OMC while 30% LZMT and 12% PLC gave the least, the average OMC was obtained at 15% LZMT and 8% PLC.

California Bearing Ratio (CBR)

The CBR results at soaked condition is presented here as shown in Figure 4. It is observed that an increase in LZMT up to 20% increases the soaked CBR values of the soil for all the percentages of PLC considered, and the CBR values dropped for 25% and 30% LZMT. The black cotton

soil at its natural state produced a soaked CBR value of 2.15%. The addition of the additives increased the soaked CBR values to as high as 27.15% at 20% LZMT and 12% PLC.

According to Highway Manual Part 1, volume III: Pavements and Material Design, 2013 [9]. a poor subgrade material is one with soaked CBR value < 5%, and can only be usable as a subgrade material when treated with cementitious materials to enhance the CBR value. The soil in use has a soaked CBR value of 2.15% which affirms its problematic status.

Unconfined Compressive Strength (UCS)

The UCS results is hereby presented as shown in Figure 5. It is observed that an increase in LZMT up to 20% for 8% PLC, and up to 25% for 4% and 12% PLC increases the UCS values of the soil, after which the UCS values dropped. The black cotton soil at its natural state produced a UCS value of 98.07kN/m². The addition of the additives increased the UCS values to as high as 672.92kN/m² at 20% LZMT and 12% PLC and 675.12kN/m² at 20% LZMT and 12% PLC.

The minimum requirement of UCS for highway subgrade is 150kN/m² according to Federal Ministry of Works (FMW) - General Specification for Bridges and Road works (1997), the UCS value of the black cotton soil (BCS)



Figure 2 Compaction plot showing MDD

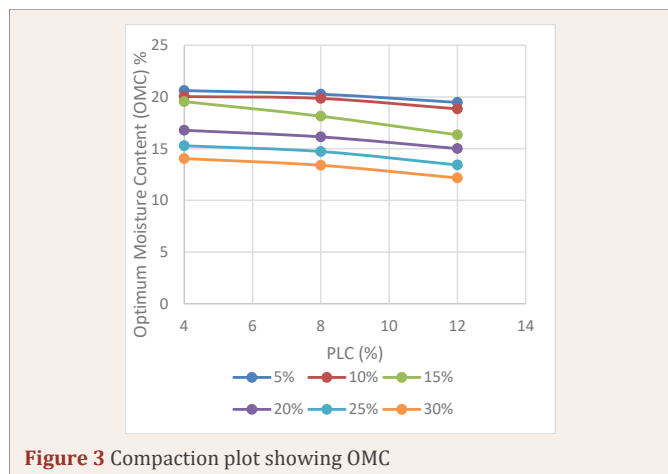


Figure 3 Compaction plot showing OMC

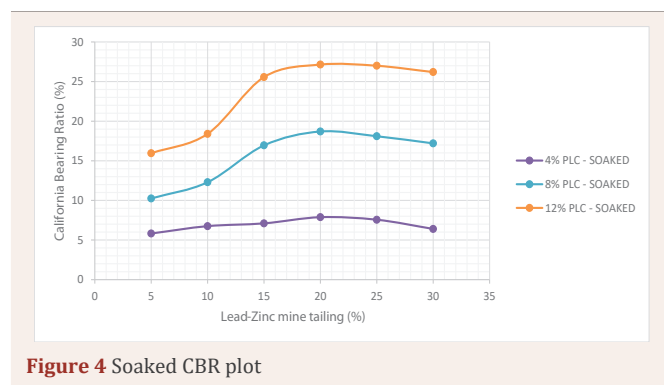


Figure 4 Soaked CBR plot

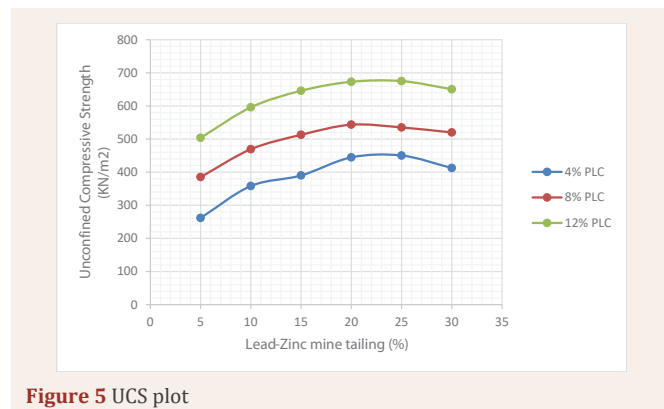


Figure 5 UCS plot

at natural state is obtained as 98.07kN/m², which makes it unfit for use at the natural state due to the fact that it does not meet up with the minimum value.

CONCLUSION

1. The CBR and UCS values of a problematic soil stabilized with LZMT and PLC has been assessed in this research, and a major improvement have been observed both with CBR and UCS results. The following conclusion have therefore been The soil is a problematic soil having soaked CBR and UCS values below the minimum requirements which therefore categorize it as problematic soil and therefore unfit for use in its natural state.

2. The Federal Ministry of works of Nigeria, Highway design manual part 1 (2013) recommended the minimum standard of soaked CBR for type 2 road (light traffic) to be 20% and 10% for sub-base, and subgrade respectively, and also recommended the UCS value for road sub-base for light traffic road to be 500 kN/m². From the Taguchi optimization technique, it can be concluded that the optimum mix of the additives required to meet up with these minimum standards for sub-base, and sub-grade CBR are 20% mine tailing, 12% cement, and 15% mine tailing, 8% cement respectively.

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