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CIVIL & ENVIRONMENTAL ENGINEERING | RESEARCH ARTICLE

Stabilization of lateritic soil from Agbara Nigeria with ceramic waste dust

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Abstract: Geotechnical properties of lateritic soil stabilized with ceramic waste dust (CWD) additive was examined. Specific tests conducted on the modified soil samples include grain-size distribution, Atterberg Limits, Proctor Compaction tests, and California Bearing Ratio tests. Lateritic soil obtained from Agbara, South-West Nigeria and pulverized ceramic materials gathered from construction site rubbles were used for the experiment. The Lateritic soil samples were mixed with ceramic dust from 0 to 30% at an incremental rate of 5%. From the analyses of test results, it was found that Liquid Limit, Plastic Limit, Plasticity Index, and Optimum Moisture Content decreased consistently with the incremental addition of ceramic dust up to 30%, whereas, Maximum Dry Density and California Bearing Ratio (Soaked and Un-soaked) increased with CWD additive. Liquid Limit decreased from 59.62% (unmixed laterite) to 35.61% (30% CWD addition). The Plastic Limit decreased linearly from 40.11% (unmixed laterite) to 23.31% (when mixed with 30% CWD). The percentages for both unsoaked and soaked California Bearing Ratio increased from 6.82% to 21.97% and 4.55% to 14.39% respectively for 5% incremental addition of CWD up to 30%. The study concluded that the use of CWD in the stabilization of lateritic soil is recommended for economic, durability, and environmental advantages.

Subjects: Concrete & Cement; Structural Engineering; Waste & Recycling; Pollution

Keywords: lateritic soil; ceramic waste dust; solid waste management; soil tests; soil stabilization

1. Introduction

Many researchers have advocated the re-use of ceramic wastes, and it is being practiced in several countries. The re-use of ceramic wastes is a sustainable means of solid waste management. Construction and demolition wastes reportedly contribute as high as 75% of globally generated

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Olumuyiwa Onakunle is an environmental engineering researcher whose areas of focus are on hydrodynamics, computational fluid mechanics, and wastewater treatment. I have conscientiously worked on various spheres of environmental engineering. I want to continually create a better and enabling environment for humans in a sustainable way.

PUBLIC INTEREST STATEMENT

Lateritic soil properties were improved for various use by partially replacing the soil with ceramic dust (gotten from construction sites). These soil replacements, however, brought an increased strength property of the soil. The laterite was mixed with ceramic dust at varying percentages with a maximum of 30% and a constant increment of 5%. The study concludes that improved ceramic dust-lateritic soil is recommended for economic, durability, and environmental advantages.

solid wastes, while ceramic wastes account for 54% of all construction wastes (Daniyal & Ahmad, 2015). In many developing countries, the subject of construction and demolition wastes re-use is important due to reports of building collapse(Akpabot, Ede, Olofinnade, & Bamigboye, 2018, 2019) and the dearth of appropriate technology for waste recycle and management (Fagbenle & Oluwunmi, 2010; Omole, Isiorho, & Ndambuki, 2016). Ceramics have high clay mineral content, and at an atomic level, silica, aluminum, iron oxide, and Calcium Oxide account for over 94% of its constituent (Juan et al., 2010). Ceramics are formed from a process whereby clayey materials are dehydrated and subject to furnace heat at temperatures up to 1000°C (Juan et al., 2010). This composition gives ceramics the required mechanical properties that make it useful as a substitute in materials used for sub-grade road construction or aggregate in concrete (Juan et al., 2010). In Nigeria, ceramics are abundantly found as it constitutes a major part of the construction process. Therefore, ceramic wastes are readily available as construction is in a continuum in Nigeria (developing country). The percentage composition of the ceramic dust is as follows: SiO_2 − 57.14, Al_2O_3 − 25.24, CaO −1.88, Fe_2O_3 − 6.53, K_2O −3.89, MgO −1.11, MnO −0.02, Na_2O −1.81, P_2O_5 − 0.11, TiO_2 − 0.68, SO_3 − 0.01.

Laterite is also a clayey material, which is reddish in coloration. It swells significantly when in contact with water and shrinks when dried out, forming topsoil in some tropical or subtropical zones and often used for construction (Sabat, 2012). Lateritic soils are commonly used for construction in many countries. Lateritic soil, in its natural form, has a low bearing capacity and low strength due to high clayey content (Amu, Ogunniyi, & Oladeji, 2016). When the lateritic soil contains a significant amount of clay material, its stability and strength cannot be guaranteed under load in the presence of moisture (Alhassan, 2008). The plasticity of the soil may result in fractures and damage to pavement, roadways, building foundations, or any civil engineering construction projects. Failure of highway pavements are commonplace on the Nigeria highway systems (Jegeda, 2000), hence the need for improvement in strength and durability of lateritic soil; although. These failures have urged many researchers towards finding alternative materials that can be sourced locally at low costs to improve soil properties (Bello, Ige, & Ayodele, 2015; Jegeda, 2000). Improvement of soils can be achieved by stabilization or modification or both (Bello et al., 2015). Stabilization is a treatment process that improves the strength and durability of soil such that its suitability for construction is heightened (Alhassan, 2008). The effective use of waste materials has been extensively studied for construction due to high construction costs and need conservation of biodiversity (Awoyera, Akinmusuru, & Ndambuki, 2016). The propensity to use ceramic waste as an aggregate material for construction is fast-growing (Awoyera, Ndambuki, Akinmusuru, & Omole, 2016). Ceramic based lateritic concrete performed considerably well in comparison with the conventional concrete, which, in return, has the advantage of waste reduction (Awoyera et al., 2016). This study reveals the optimal engineering properties of stabilized lateritic soil at varying mix ratios of ceramic dust for various construction purposes. Figures 1 and 2 show the lateritic soil and ceramic dust used in the research.

Figure 1. Laterite soil from South-west of Nigeria (Agbara).

Figure 2. Ceramic waste dust from an industrial site.

Diverse studies have been carried out by researchers around the world to achieve better soil properties using various industrial and agricultural wastes. These wastes include the use of palm kernel ash, fly-ash, rice husk ash, ceramic waste dust, cement, lime, olives, etc. (Akintunde, 2010; Amu et al., 2016; Awoyera et al., 2016; Jegeda, 2000; Juan et al., 2010; Marto, Latifi, & Sohaei, 2013; Murthy, 2012; Ogungbire et al., 2018; Otoko & Pedro, 2014; Rashid, Latifi, Meehan, & Manahiloh, 2017; Sani, Makwin, & Sule, 2019; Yunus, Yung, & Abdullah, 2013). E-Jalal, Naseem, Hussain, and Tariq (2017) stated that the maximum dry density (MDD) increases while the optimum moisture content (OMC) decreases with the addition of ceramic dust up to 40%. It also showed that sawdust ash improved geotechnical properties of the soil (Akintunde, 2010; Ogunribido, 2012).

2. Methodology

The soil used to prepare the mixes was first air-dried, then sieved through a 2-mm mesh to confirm the uniformity of the soil. The ceramic waste dust was passed through sieve No. 200 for the consistency of dust. The next step was conducted following clause 3.3.4.2 of BS 1377: Part 4: (British standard institute, 1990). This action included the determination of the OMC for the natural lateritic soil. Then the lateritic soil mixed with different amounts of additive (ceramic waste dust). Subsequently, a specified amount of ceramic waste dust was mixed with distilled water and added to the soil. For the untreated soil, only distilled water was added to the soil. Varying ceramic dust contents of 0, 5, 10, 15, 20, 25, and 30% by weight of dry soils were added to the lateritic soil samples.

For this research, lateritic soil from the South-West zone of Nigeria (Agbara) was collected in large sacks. The different tests like Atterberg's Consistency Limit tests, Specific Gravity, Compaction, and California Bearing Ratio (CBR) tests were performed on the soil samples at the Soil Testing Laboratory of Julius Berger Construction Company, Apapa in Lagos. Similarly, ceramic wastes obtained from industrial and construction sites were collected in bags. These ceramic (tiles) wastes were pulverized into a powdered form using a locally fabricated milling machine. For the different experiments, the soil sample was mixed with the ceramic waste dust from 0 to 30% at an interval of 5%. In total, seven mixes were prepared. Liquid Limit tests, Plastic Limit tests, Proctor Compaction tests, and California Bearing Ratio (CBR) tests were conducted on these samples/mixes according to **ASTM** D1557 Code. The CBR was done for both soaked and un-soaked samples. The un-soaked California bearing ratio (UCBR) test was performed immediately while the soaked California bearing ratio (SCBR) was performed after ninety-six (96) hours of soaking in water.

3. Results and discussion

The results of Specific Gravity test, Atterberg's Consistency Limit tests: (Plastic limit (PL), Liquid limit (LL) and Plasticity index), California Bearing Ratio (soaked and un-soaked) tests and the Proctor

Compaction (OMC and MDD) tests performed following **ASTM** D1557 standards on the retrieved soil are presented in Table 1. While the results of the Specific Gravity test and the Proctor Compaction test performed on the ceramic dust are shown in Table 2.

3.1. Grain size distribution

Grain size distribution is essential to the stability of the soil. A well-graded soil means there are particles of different sizes present in the soil. The smaller particles fill the voids created by more massive particles, leading to stability and fewer pores for water to occupy. The grain size distribution is shown in Tables 3 & 4 and Figure 3 for the lateritic soil classification. The coefficient of Uniformity (C_u) obtained was 31.467 (Equation (1))

Table 1. Geo-technical properties of Agbara soil

Specific gravity	Atterberg's limit (%)			OMC (%)	MDD (KN/m^3)	UCBR (%)	SCBR (%)
	P. L	L.L	P. I				
2.57	40.11	59.62	19.51	19.35	17	6.82	4.55

Table 2. Geotechnical properties of ceramic dust

Specific Gravity	OMC (%)	MDD (KN/m^3)
2.84	16.11	22.6

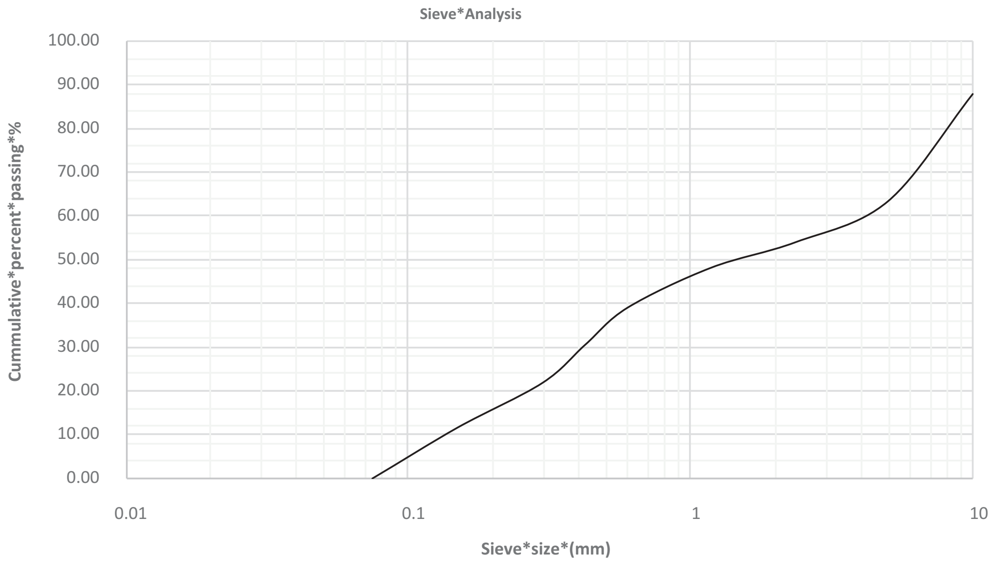
Table 3. Weight of grain size passing sieve No. 200

Sieve analysis	
Soil sample	Weight (g)
The initial dry weight of the sample	500
Weight of dry sample after washing	421
Washed through sieve No. 200	79

Table 4. Grain size distribution for soil sample

BS Sieve Size (mm)	Weight of sample retained (g)	% Retained	cumulative Weight (g)	Cumulative Percentage Retained	Percentage Passing %
63.000	0.00	0.00	0.00	0.00	100.00
37.500	0.00	0.00	0.00	0.00	100.00
19.000	0.00	0.00	0.00	0.00	100.00
10.000	50.70	12.04	50.70	12.04	87.96
5.000	103.30	24.54	154.00	36.58	63.42
2.360	39.40	9.36	193.40	45.94	54.06
1.180	50.80	12.07	244.20	58.00	42.00
0.600	42.50	10.10	286.70	68.10	31.90
0.425	45.90	10.90	332.60	79.00	21.00
0.300	46.70	11.09	379.30	90.10	9.90
0.150	24.70	5.87	404.00	95.96	4.04
0.075	17.00	4.04	421.00	100.00	0.00

Figure 3. Grain size distribution curve for soil sample.



Which is higher than the required minimum of 6 for well-graded sand, and the co-efficient of Curvature (C_c) was 0.508 (Equation (2)), which is below the range of 1 and 3 for a well-graded soil. The soil can, therefore, be classified as a Poorly Graded Sand (SP) according to **ASTM** D2487.

Coefficient of uniformity (Cu)

$$Cu = \frac{D60}{D10} = \frac{2.36}{0.075} = 31.4666667 \quad (1)$$

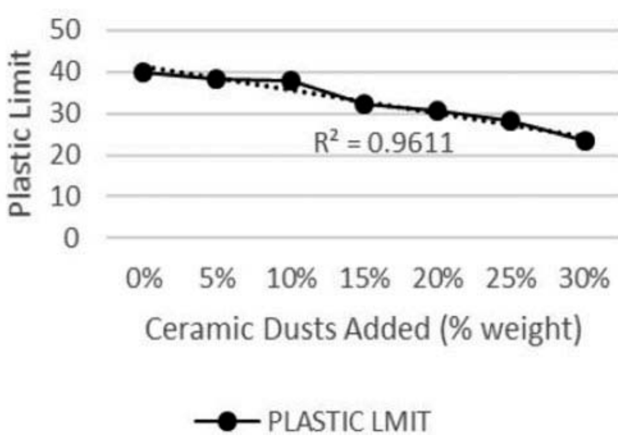
Coefficient of curvature (Cc)

$$Cc = \frac{D30^2}{D60 \times D10} = \frac{0.3^2}{2.36 \times 0.075} = \frac{0.09}{0.177} = 0.508474576 \quad (2)$$

3.2. Atterberg's consistency limit tests

Atterberg limits, consisting of liquid limits, plastic limits, and shrinkage limit, measures the unique characteristics of soils concerning water content. Different soils demonstrate different behaviors at different moisture content levels, and these behaviors may be desirable or not, depending on the context of use. Figure 4–6 illustrate a detailed graphical arrangement for different percentages of

Figure 4. Plot of plastic limit with ceramic dust addition.



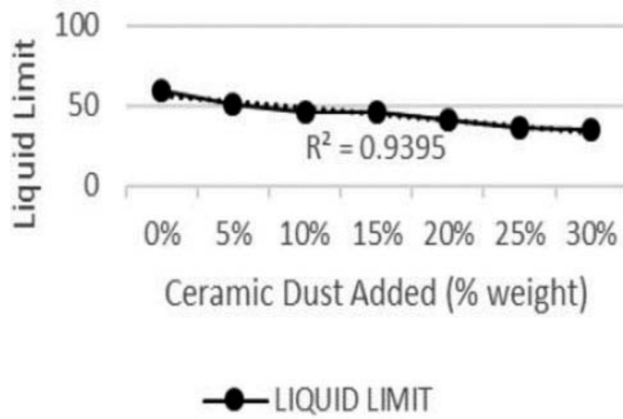


Figure 5. Plot of liquid limit with ceramic dust addition.

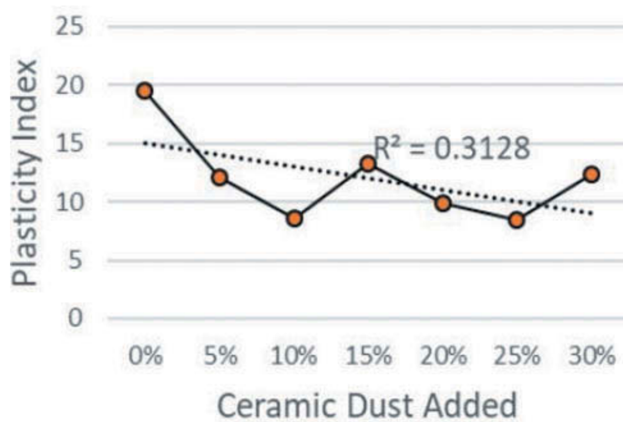


Figure 6. Plasticity index with ceramic dust addition.

Ceramic Dust at intervals of 5, 10, 15, 20, 25 and 30% (by weight) in the obtained soil sample. From Figure 4, it is evident that the increasing amount of Ceramic Dust caused a progressive reduction in the Plastic limit values from 40.11% (unmixed soil) to 23.31% (when mixed with 30% Ceramic Waste Dust). A decrease in Liquid Limit values was also observed with the addition of ceramic dust. These reductions are attributed to the presence of calcium oxide (CaO) in the ceramic waste dust, which reacts with water particles in the lateritic soil, thereby lowering its moisture content. In the process, forming mortar ($Ca(OH)_2$), which is a sturdy material. Figure 5 shows the reduction in Liquid Limit values from 59.62% (for unmixed soil sample) to a significantly decreased value of 35.61% (when blended with 30% Ceramic Waste Dust), with a coefficient of determination of 0.94.

Figure 6 shows the reduction in Plasticity Index values from 19.51% (100% lateritic soil) to a significantly decreased value of 12.3% (30% ceramic dust). This variation in the Plasticity Index value is a significant indicator of soil stabilization. That is, the plasticity index moving from high plasticity to medium plasticity with peak points at 15% and 30% ceramic dust addition. At an R^2 value of 0.3127 (insignificant), it is shown that the addition of ceramic dust to the lateritic soil samples has minimal impact on soil modification.

3.3. Proctor compaction tests

Proctor compaction test consists of a series of tests that indicate the OMC at which a soil material attains optimum density and attains MDD. The results of compaction tests targeted soil samples blended with various percentages of ceramic waste dust are illustrated in Figures 7 and 8. It is evident from Figure 8 that the MDD shows an increasing trend, whereas the OMC in Figure 7 is

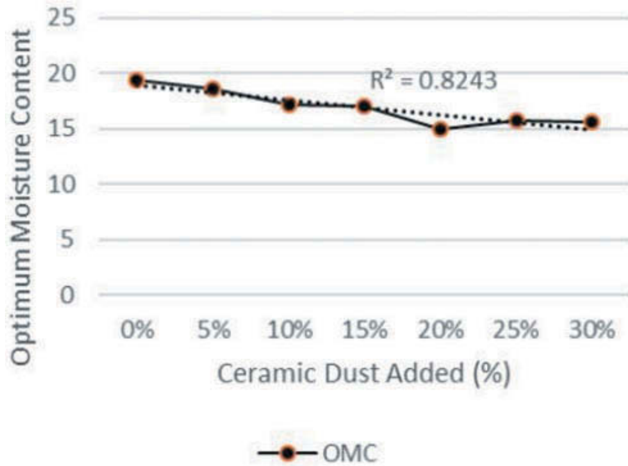


Figure 7. Plot of optimum moisture content (OMC) with ceramic dust addition.

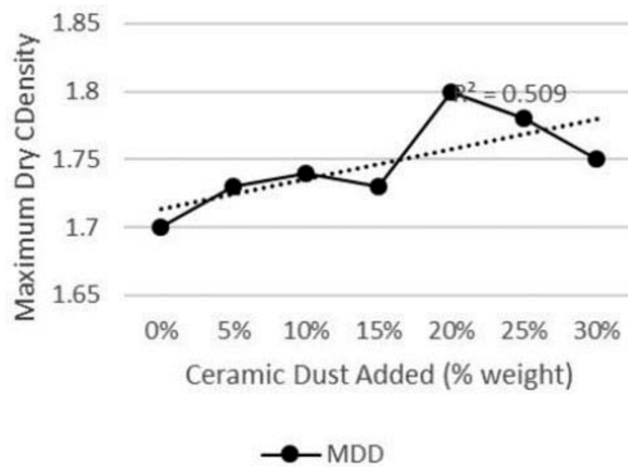


Figure 8. Maximum dry density with ceramic dust addition.

lowered upon the addition of ceramic dust, which agrees with reason. The MDD for untreated soil was 17 kN/m^{3,} whereas it increased up to 17.5 kN/m^3 (when mixed with 30% ceramic dust waste). This is attributed to the replacement of additive particles having a heavier weight and specific gravity value than the lateritic soil (Tables 1 and 2). The OMC is observed to be reduced when the ceramic dust additive is added from 0 to 30% with values of 19.35% to 15.65%, respectively, with a coefficient of determination of 0.82. Thus, the absorption of water molecules by the additive (ceramic waste dust) led to a reduction in OMC.

3.4. California bearing ratio tests

California Bearing Ratio (CBR) is a test for measuring the bearing strength properties of natural road base-course and sub-grades. Soaked and un-soaked California Bearing Ratio with ceramic dust additions are shown in Figures 9 and 10, respectively. It is evident from Figures 9 & 10 that the CBR values show an increasing trend. The unsoaked CBR for untreated soil was 6.82%, but it increased progressively to 21.97% at 30% ceramic dust mix with a coefficient of determination of 0.99. The mechanical strength of the lateritic soil increased significantly, with the addition of ceramic dust up to 30%. The soaked CBR for untreated soil was 4.55% but increased progressively to 14.39% at 30% ceramic dust mix with a co-efficient of determination of 0.99. However, both results indicate that a better CBR was achieved without soaking (Figs. 9 and 10). The force per unit area of the soil increased with the addition of Ceramic Dust up to 30%; therefore, the mechanical strength was improved.

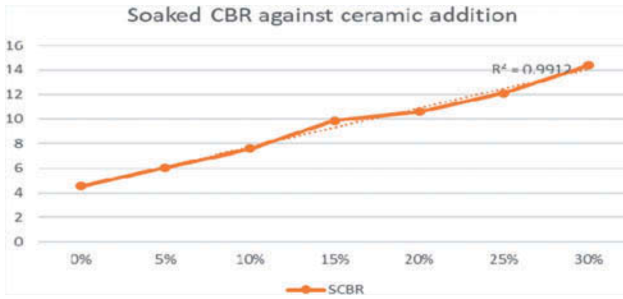


Figure 9. Soaked CBR with ceramic dust addition.

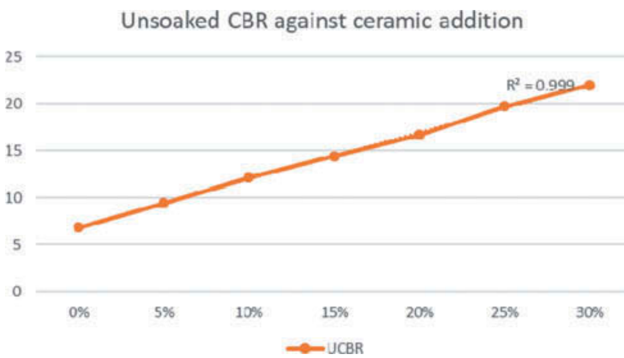


Figure 10. Un-soaked CBR with ceramic dust addition.

4. Conclusion

From this study, it was deduced that ceramic waste dust (CWD) is a useful material in enhancing the strength properties of lateritic soil. From the standpoint of economy and strength, it is recommended that ceramic dust, up to 30%, can be utilized for soil improvement (stabilization). This had broad implications on environmental conservation. Laterite material is mostly quarried thus leaving vast areas bare of tree covers and open to erosion and mudslide. However, with as much as 30% replacement of laterite with ceramic waste dust, a large portion of the environment can be conserved over time. Furthermore, ceramic wastes, which constitute a more significant percentage of construction wastes globally, will find use in road construction, thereby reducing the waste load on the environment. Also, observing the substantial improvement in the CBR-value of stabilized soil using CWD presents a cheaper alternative for soil stabilization, which may be deployed for road construction purposes.

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Correction
This article has been republished with minor changes. These changes do not impact the academic content of the article.

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