Effect of Ceramic Tile Waste Dust on Engineering Properties of Shale Soil

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ABSTRACT

The study investigated effect of ceramic tile waste dust (CTWD) on some engineering properties of shale soil treated with 0, 2, 4, 6, 8, 10, 12, 14 and 16% of CTWD by dry weight of soil for use in road construction. Samples were subjected to index and compaction tests using British Standard light (BSL) compaction energy. The maximum dry densities (MDD) increased with increase in CTWD contents. The MDD value of 1.52 Mg/m^3 recorded for the natural soil increased to 1.58, 1.59 and 1.60 Mg/m^3 at 4, 6 and 14% CTWD contents respectively. On the other hand, optimum moisture content (OMC) values decreased with increase in CTWD contents. Statistical analysis of variance on test results showed that CTWD blend has significant effect on compaction properties of treated shale soil. There were also noticeable increments in California bearing ratio (CBR), unconfined compressive strength (UCS) as well as resistance to loss in strength values with increase in CTWD content. The regression analysis results also showed a good relationship between dependent (MDD, OMC, CBR, UCS and resistance to loss in strength (durability)) and the independent (CTWD content, gravel fraction, sand fraction, specific gravity, plasticity index, fine fraction, compactive effort) parameters considered as demonstrated by the coefficient of multiple determinations (R^2) values of 0.999, 0.975, 0.971, 0.989 and 0.991 for MDD, OMC, CBR, UCS and durability respectively. Although the UCS values increased, the peak UCS value of 188.7 kN/m^2 recorded at 16% CTWD treatment after 28 days of curing could not satisfy the Nigerian General Specifications (1997) requirement of 1720 kN/m^2 for use as road base course for lightly trafficked roads. It is therefore recommended that CTWD be used along with more potent additive such as cement, lime or bitumen for probable adequate stabilization.

Keywords: *Ceramic tile waste dust, compaction, shale, strength properties*

1. INTRODUCTION

Shale is a form of sedimentary rock which is composed of fine-grained (silt and clay) particles compacted over time (Okeke and Okogbue, 2011). Shale soil which is expansive in nature covers wide range of area in Makurdi metropolis especially at the Nigerian Air Force base, University of Agriculture Makurdi and some parts of Wadata areas in Nigeria. Structures and roads founded on shale soils suffer significant structural damage ranging from cracks on buildings as well as heaving of paved surfaces (Iorliam *et al.*, 2012). To address the peculiar problems associated with shale soil during construction is to replace the poor soil with quality material or to stabilize the soil. One method that enjoys wide application is the use of chemical additives to improve the engineering properties of marginal soils (Sharma *et al.*, 2017; Rajbeer *et al.*, 2018).

The amount of waste generated and its impact on the environment is of grave worry to the concerned authorities globally. As a result of this, conscious effort towards waste minimization through process control has been emphasized even though, it is almost impossible to completely eliminate waste generation (Chandana, 2013). Waste has been categorized into construction and demolition wastes, industrial waste, domestic waste as well as agricultural waste. It is reported that about 30% of materials comes out as waste in the production of ceramics (Binichi, 2007; Sharma *et al.*, 2017). Reuse of construction and demolition waste such as ceramic tile waste dust in the stabilization of expansive shale soil would have environmental as well as economic benefits (Rajbeer *et al.,* 2018). Similar additives (dust/powdered) has been used with some level of success by many researchers (Srinivasulu and Rao, 1995; Swami, 2002; Palaniappan and Stalin, 2009; Ene and Okagbue, 2009; Sabat and Nanda, 2011; Sabat, 2012; Abd EI Aziz and Abo-Hashema, 2012; Osinubi *et al.*, 2015; Ajay and Suneet, 2016; Etim *et al.,* 2017; Kanyi *et al.,* 2017; Sharma *et al.,* 2017; Rajbeer *et al.,* 2018).

This study aimed at evaluating the effect of ceramic tile waste dust on the engineering properties of shale soils. The specific objectives include determination of the changes in the index, compaction and strength properties of the treated soil with 0, 2, 4, 6, 8, 10, 12, 14, and 16% of CTWD by dry weight of soil for use in road construction.

2. METHODOLOGY

2.1 Materials

2.1.1 Soil

The disturbed soil specimen used for the study was obtained from North core, University of Agriculture Makurdi (UAM), Benue State, Nigeria at a depth of about 0.5m to avoid the inclusion of organic matter. The soil specimen were transported to the Department of Civil Engineering Soils Research Laboratory, UAM and air dried before pulverizing to obtain particles passing required sieve size as indicated in BS1377 (1990) for each tests. At point of collection, soil samples were sealed in plastic bag to avoid moisture loss during transportation in order to determine natural moisture content.

2.1.2 Ceramic tile waste dust (CTWD)

The ceramic tile wastes (see plate 1A) were collected from construction and demolition sites within Makurdi metropolis and were broken into small pieces by using a hammer. The smaller pieces were fed into a Los Angeles abrasion testing machine to make it further smaller particles in size. These smaller particles of tiles waste are known as CTWD (see plate 1B).

Plate 1: A: Ceramic Tiles Waste from Demolition Site and B: CTWD after Grinding

2.2 Methods

2.2.1 Index properties

Index properties tests (natural moisture content, sieve analysis, Atterberg limits and specific gravity) for both natural and treated soil were performed based on procedures described in BS1377 (1990) and BS1924 (1990) for natural and stabilized soils, respectively.

2.2.2 Compaction

The pulverized soil were passed through sieve with 4.75 mm aperture and treated using 0, 2, 4, 6, 8, 10, 12, 14 and 16% CTWD by dry weight of soil. All tests involving compaction were carried out using the BSL energy level based on procedures of BS1377 (BSI, 1990) and BS1924 (1990). The BSL compaction involved the use of 2.5 kg rammer falling through 300 mm onto three layers in a BS (Proctor) mould, each layer receiving 27 blows.

3. RESULTS AND DISCUSSION

3.1 Physical Properties of the Materials Used

Results of preliminary tests performed on the index properties of the untreated soil showed that the soil is an A-7-6 soil according to AASHTHO soil classification system with natural moisture content of 19.3% and specific gravity value of 2.32. The soil Atterberg limits (liquid limits (LL), plastic limits (PL) and the plasticity index (PI)) values were 46.6, 31.8and 14.8%, respectively. The summary of these properties are shown in table 1. These results showed that the soil did not meet the minimum standard desired for most geotechnical construction works especially for sub-base and base courses in highway construction (Osinubi and Medubi, 1997).

Table 1: Properties of Natural Makurdi Shale

Properties	Quantity
Percentage passing BS sieve No. 200 (%)	87
Natural moisture content (%)	19.30
Liquid limit (%)	46.60
Plastic limit (%)	31.80
Plasticity index (%)	14.80
Linear shrinkage (%)	13.60
Specific gravity	2.32
AASHTO classification	A-7-6
USCS classification	CH
Maximum dry density (Mg/m^3)	1.52
Optimum moisture content (%)	20.80
CBR (%)	1.66
UCS (kN/m^2)	78.3
Soil color	Yellowish-green

The result of chemical composition of Makurdi shale and that of CTWD is presented in Table 2. The results showed that CTWD is a pozzolanic material (ASTM, 2013). From the results, the relatively little amount of CaO in shale soil (0.26%) was supplemented by the calcium oxide present in CTWD (3.01%) during the stabilization process. The higher silicon oxide content (71.82%) in CTWD also aided those in shale soil (49.02%) to provide the required silica oxides needed for stabilization. Also, the percentage by weight of Al_2O_3 and Fe_2O_3 in both Shale soil and CTWD were also complementary during stabilization. The Shale soil and CTWD would therefore act together to modify and stabilize the natural soil. Figure 1 showed the particle size distribution curve of the natural soil obtained from the hydrometer test. The result showed that the soil contain high amount of fine fraction and is not well graded and thus requiring modification to meet construction requirements.

Table 2: Chemical Compositions of Makurdi Shale and CTWD

Oxide Composition	Concentration (% by weight)	
	Makurdi shale*	**CTWD**
SiO_2	49.02	71.82
P_2O_5	0.50	0.25
SO_3	-	3.62
K_2O	1.85	0.97
CaO	0.26	3.01
TiO_2	1.98	5.04
V_2O_5	-	-
Cr_2O_3	-	0.08
Mn_2O_3	0.03	0.08
Fe_2O_3	8.37	2.47
Al_2O_3	25.24	11.18
MgO	1.16	0.59
Na_2O	2.57	0.69
Cl	-	0.04
ZnO	-	0.10
SrO	-	0.07
LOI	-	-

*Iorliam *et al. (*2012)

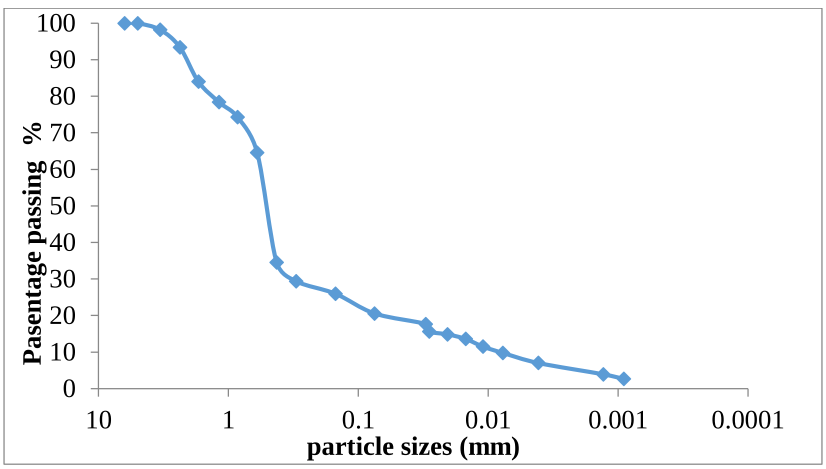

Figure 1: Particle Size Distribution Curve for the Natural Soil.

3.2 Effect of CTWD on Specific Gravity of Shale Soil

The effect of specific gravity with varying CTWD is presented in Figure 2. The results showed an increase in specific gravity values with increased in CTWD contents. The specific gravity increased from 2.32 for the natural soil to a peak value of 2.52 at 16% CTWD-soil blend. The observed trend may be due to CTWD having higher specific gravity (2.81) value relative to the shale soil which has specific gravity value of 2.32. At higher CTWD content, more of CTWD replaces the soil thus leading to an increase in the specific gravity of the resulting soil matrix. Similar trends were also reported by Sabat (2011), Sabat and Bose (2013) and Kanyi *et al.* (2017).

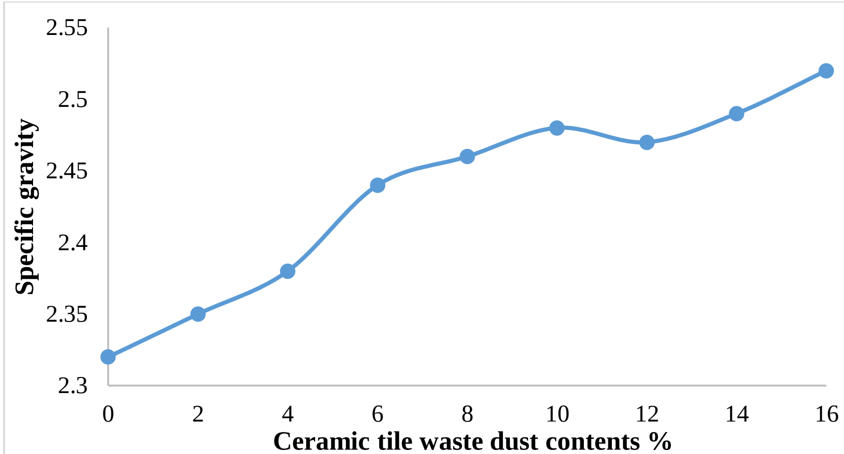

Figure 2: Variation of Specific Gravity of Soil-CTWD Blend

3.3 Effect of CTWD on Compaction Characteristics of Shale Soil

3.3.1 Effect of CTWD on maximum dry density (MDD)

The results of varying CTWD-soil mixtures on MDD compacted with BSL compactive effort is presented in Figure 3. It was observed from the figure that, increase in CTWD content resulted to a general increase in MDD values. The MDD value of 1.52 mg/m^3 recorded for the natural soil increased to 1.58, 1.60 and 1.62 Mg/m^3 at 4, 14 and 16 % CTWD contents respectively. Similar behavior was reported by Sabat (2012). The observed increase in MDD values at higher CTWD content may be due to high specific gravity of CTWD (2.81) particles replacing soil particle with lower specific gravity (2.52) in the resulting soil-CTWD blend. Also, it might be as a result of reduction in amount of pore spaces in the resulting soil-CTWD mixtures after compaction which brings more soil and CTWD particles together thereby leading to increase in MDD values. Furthermore, the flocculation and agglomeration of fine particles due cation exchange reaction might be responsible for the increase in maximum dry density (Lees *et al.*, 1982; Osinubi *et al.*, 2015; Etim *et al.*, 2017; Kanyi *et al.*, 2017). The results are in agreement with findings reported by Hossain *et al.* (2007) and Amu *et al.* (2011). ANOVA on the MDD values showed that the relative effects of CTWD on Makurdi shale was $F_{Cal} = 16.04 > F_{Crit} = 3.01$ as shown in Table 3. This means that CTWD has significant effect on MDD since its Fcal is greater than the Fcrit.

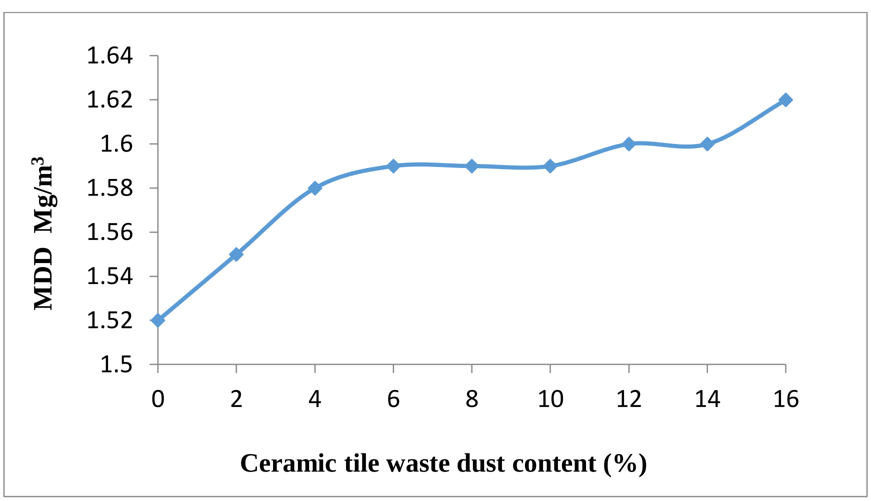

Figure 3: Variation of MDD with CTWD-Soil Mixtures

3.3.2 Effect of CTWD on optimum moisture content (OMC)

The effect of OMC on CTWD-soil mixtures is shown in Figure 4. It was observed from the figure that an increase in CTWD content resulted to a general decrease in the OMC values. OMC value of 20.8% recorded for the natural soil dropped to 17.3% when treated with 16% CTWD content. The observed trend is in agreement with other researchers (Sherma *et al.*, 2017; Rajbeer *et al.*, 2018). The observed behaviour may be due to replacement of soil particles with CTWD particles which increased the attraction for water molecules and hence a decrease in OMC. The findings are also in agreement with those of Basha *et al.* (2005) and Sabat (2012). The results of ANOVA of the OMC showed that the relative effects of CTWD on Makurdi shale was $F_{Cal} = 24.04 > F_{Crit} = 3.01$ as shown in Table 3.

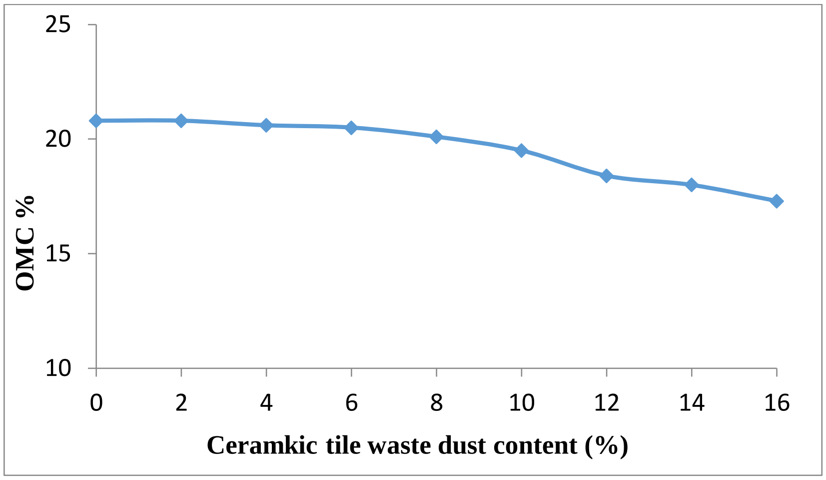

Figure 4: Variation of OMC with CTWD-Soil Mixtures

Table 3: One -Way Analysis of Variance for Compaction Characteristics of Soil-CTWD Mixtures

Properties	Source of Variation	df	Fcal	p-Value	Fcrit	Remarks
MDD	CTWD	4	16.04	1.80E-05	3.01	SS
OMC	CTWD	4	24.04	1.35E-06	3.01	SS

df – degree of freedom

3.3.3 Regression analysis for MDD and OMC

Regression analysis is a statistical test which presents the relationship between the dependent and independent variables. The extent to which the independent variables influence the dependent variable is a function of the resultant coefficient of multiple determinations (R^2). Geotechnical properties considered for this analysis include: CTWD content, gravel fraction, sand fraction and percentage fine fractions as independent variables. The specific gravity was also considered as independent variable while the compactive effort was used as a deterministic parameter. These were based on the fact that materials used for pavement depend mainly on their particle size characteristics, the nature and strength of the particles and the degree to which the soils have been compacted (Gidigasu, 1976). The modeled regression equations for MDD and OMC are shown in equations 1 and 2 respectively. The R^2 value showed a strong relationship between maximum dry density and the parameters with $R^2 = 0.999$, while R^2 value of 0.975 was recorded for optimum moisture content.

$$MDD = -0.4669 + 0.0345CTWD - 0.0073Gr - 0.4116Gs + 0.1949PI + 0.003Sa + 0.0069Pf + 0.2328CE \quad (1)$$

$$OMC = -71.927 + 0.2177CTWD - 0.1488Gr + 12.578Gs + 4.1213PI + 0.0997Sa + 0.1388Pf - 4.4437CE \quad (2)$$

Where; MDD = Maximum dry density, OMC = Optimum moisture content, CTWD = Ceramic tile waste dust content, Gr = Gravel fraction, Sa = Sand fraction, Gs = Specific gravity, PI = plasticity index, Pf = Fine fraction, CE = Compactive effort.

3.4 Effect of CTWD on Strength Characteristics of Shale Soil

3.4.1 Effect of CTWD on the California bearing ratio (CBR)

The California Bearing Ratio (CBR) test is generally used to evaluate the strength of materials for use as sub-grade soil, sub-base and the base courses in the design and construction of airfield and road pavement (Liu and Evett, 2003). The result of varying CTWD-Soil blend on CBR values is presented in Figure 5. The un-soaked CBR values of the soil sample increased upon stabilization with CTWD content. The increase in un-soaked CBR values may be due to the formation of cementitious compounds resulting from the reaction between calcium from the CTWD, silica and iron oxides from the soil to be treated leading to increase in the CBR values (Figure 5). The increase in the CBR values however did not meet the minimum requirement of 30 and 80% for sub-base and base course of roads respectively stipulated by Nigerian General Specifications (1997).

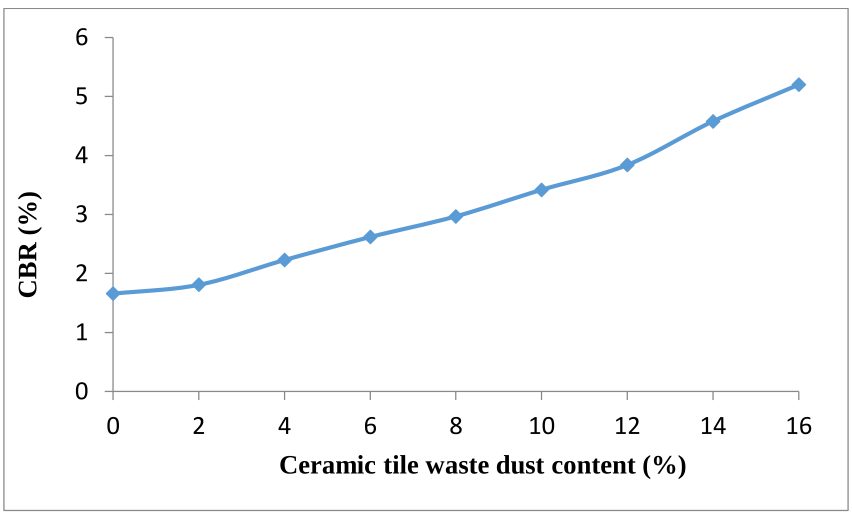

Figure 5: Variation of CBR with CTWD-Soil mixtures

3.4.2 Effect of CTWD on the UCS of shale soil

The results of unconfined compressive strength (UCS) of the stabilized soil are presented in Figure 6 for 7, 14 and 28 days curing. It was observed that the UCS values increased with increase in CTWD content. The increase in UCS values could be due to increased pozzolanic reaction after curing which resulted in the formation of calcium silicate hydrates and micro fabric changes which is responsible for increased strength (Kedzi, 1979). The UCS values also increased with increase in the curing time (Figure 6). The result is consistent with previous research findings (Hossain *et al.*, 2007; Harichane *et al.*, 2011). Although the UCS of the treated samples increased with increased percentage of CTWD content, they are lower than 1720 kN/m^2 recommended by the Nigerian General Specifications (1997) for use as road base course for lightly trafficked roads.

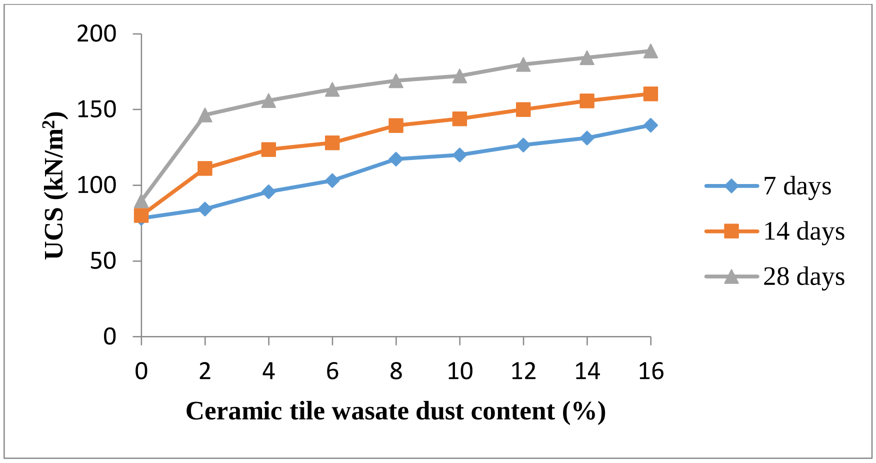

Figure 6: Variation of UCS with CTWD-Soil mixtures

3.4.3 Effect of CTWD on the durability of shale soil

The same trend as with that of CBR and UCS was also observed with the durability test as shown in Figure 7. The samples did not withstand the durability test after 4 days soaking period suggested by Ola (1991). The resistance to loss in strength for the untreated specimens was 8% (i.e., 92% loss in strength). The resistance to loss in strength increased from 8% for untreated Makurdi shale to 67% at a combination of 16% CTWD. The increase in durability shows that CTWD has a long time strength improvement capacity. The loss in strength recorded is more than the maximum 20% allowable loss in strength after 4 days soaking period prescribed by Ola (1991). It is therefore advised to incorporate other potent additives such as cement, lime and bitumen in the soil to improve its durability.

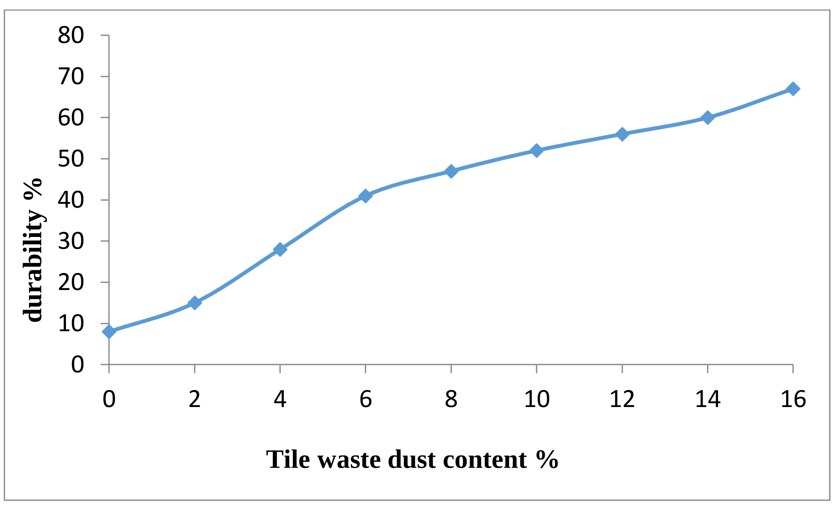

Figure 7: Variation of durability with CTWD-Soil mixtures

3.4.4 Regression analysis for CBR, UCS and durability

The regression analysis carried out on CBR, UCS and durability as dependent variables showed that these parameters are strongly correlated with the independent variables. The independent variables considered include; CTWD content, percentage fine and plasticity index using compactive effort as the deterministic parameter. The R^2 values for the resulting regression equations 3, 4 and 5 were 0.971, 0.989 and 0.991 for CBR, UCS and durability respectively.

$$CBR = -0.8248 + 0.3283CTWD - 0.0085PF + 0.1466PI + 0.3271CE \quad (3)$$

$$UCS = 46.2369 + 2.3964CTWD + 0.3183PF + 2.3776PI - 13.2546CE \quad (4)$$

$$RLS = 112.6631 + 0.3038CTWD + 0.2744PF - 7.2099PI - 4.6963CE \quad (5)$$

Where; CBR = California bearing ratio, CTWD = Ceramic tile waste dust content, PI = Plasticity index, Pf = Fine fraction, CE = Compactive effort, UCS = Unconfined compressive strength, RLS = Resistance to loss in strength (durability).

4. CONCLUSION

The study evaluated the effect of ceramic tile waste dust (CTWD) on some geotechnical properties of shale soil. On the basis of the tests results the following conclusions were drawn: The MDD values increased with increment in CTWD contents. The MDD value of 1.52 Mg/m^3 recorded for the natural soil increased to 1.58, 1.59 and 1.60 Mg/m^3 for 4, 6 and 14% CTWD contents respectively. On the other hand, OMC values decreased with increase in CTWD contents. Statistical analysis of variance on test results showed that CTWD blend has significant effect on compaction properties of treated shale soil. There were also noticeable increments in CBR, UCS as well as resistance to loss in strength value with increase in CTWD content. The regression analysis results also showed a good relationship between dependent (MDD, OMC, CBR, UCS and resistance to loss in strength (durability) and the independent (CTWD content, gravel fraction, sand fraction, specific gravity, plasticity index, fine fraction, compactive effort) parameters as demonstrated by the coefficient of multiple determinations (R^2) values of 0.999, 0.975, 0.971, 0.989 and 0.991 for MDD, OMC, CBR, UCS and durability respectively. Although the UCS values increased, the peak UCS value of 188.7 kN/m^2 at 16 % CTWD treatment after 28 days of curing could not satisfy the Nigerian General Specifications (1997) requirement of 1720 kN/m^2 for use as road base course for lightly trafficked roads. It is therefore recommended that CTWD be used along with more potent additive such as cement, lime or bitumen for probable adequate stabilization.

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