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Effect of Ceramic Waste on Geotechnical Properties of Cement Stabilized Clay Soil

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ABSTRACT.

A clay soil collected at Barkindo along Lamurde-Gombe road in Numan Local Government area of Gombe State, Nigeria, was stabilized with 0, 2, 4 and 6% cement which was admixed with 0, 10, 20, 30 and 40% Ceramic waste dust (CWD) each. Index properties and microstructural tests were conducted on the untreated clay soil while compaction and unconfined compressive strength tests were carried out on the untreated clay and clay soil admixed with varied composition of cement and CWD. Results from index properties showed that the clay classified as of high plasticity based on unified soil classification system. The microstructural results revealed that the clay consist of quartz, microcline, kaolinite, brushite and gypsum. The maximum dry densities (MDD) were observed to reduce with increase in cement and CWD while the optimum moisture content (OMC) reduces in the same order. The unconfined compressive strength (UCS) increased with increase in CWD for specific cement addition, to maximum of 30% CWD after which the values were observed to drop. 30% CWD is therefore the optimal CWD required for maximum UCS strength. A maximum of 2700kN/m^2 was recorded at 6% cement and 30% CWD after 90days of curing. This maximum value satisfied the requirement for a stabilized material to be used as base course for highly trafficked roads. Significant increase in UCS was also observed with increase in curing days which signifies the existence of Pozzolanic reaction in the mixture. 30% CWD can be used for effective stabilization of cement stabilized clay soil.

KEYWORDS: *Black cotton soil, Ceramic waste dust, Microstructure, Pozzolana Stabilization,*

1 INTRODUCTION

The increasing population of the world, especially developing nations has led to increasing demand for roadways, railways, housing facilities and other infrastructures. Soil with higher stability is required to bear the weight of these structures; generally speaking, the stability of any construction related structure indirectly or directly depends on the soil stability (Balarabe and Mary, 2015).

Soil stabilization means the improvement of the stability or bearing power of a deficient soil by the use of compaction; proportioning and the addition of suitable stabilizers or admixtures. Soil stabilization includes chemical, mechanical, physico-chemical methods to improve the soil properties. Stabilization method can generally be categorized as physical and chemical methods (Neeraj and Ahirwar, 2014).

Expansive soils swell or increase in volume in monsoon seasons and shrink or reduce in volume because of evaporation of water in dry seasons (Balarabe and Mary, 2015). Black cotton soils are parts of expansive clay soils and are derived from the weathering action of basalts and traps of deccan plateau (Gurugubelli et al, 2017). They are highly fertile for agricultural purposes but pose severe problems to the pavements, embankments and light to medium loaded residential buildings resting on them due to cyclic volumetric changes caused by moisture fluctuation. This volume change behavior is the reason for cracking to the overlying structures. The reason for this behavior is the presence of clay mineral such as montmorillonites (Gurugubelli *et al.*, 2017).

The stabilization of this swelling-shrinking clay soils requires stabilization to improve their strength and stability so as it can be used for civil engineering infrastructural development. A lot of researches (Khajuria and Chopra, 2019; Abdullah et al, 2017; Du et al, 2019; Ziao et al, 2019; Pourakbar et al, 2016; James and Pandiam, 2016; Song et al, 2019) have been conducted on clay soils using different chemicals to determine the effect of various additives on the strength and stability of these deficient soils. However, the use of ceramic waste dust have not been fully studied.

A ceramic tile is an inorganic, non-metallic, solid material. The earliest ceramics made by humans were pottery objects made from clay either by itself or mixed with other materials like silica. Later ceramics were glazed and fired to create smooth, coloured surfaces, decreasing porosity. The raw materials to form tile consists of clay mineral mined from earth crust and natural mineral such as feldspar (Neeladharan et al, Saranya, 2017). Stabilization using ceramic waste is one such waste material which can be used for improving the properties of poor clayey soils. Convenient use of ceramic waste for soil stabilization will go a long way in solving their disposal problem which can contribute to safer environment. Sabat (2016) carry out holistic study on the effect of ceramic dust on engineering properties of clay soil. The properties studied includes Atterberg limits, compaction test, unconfined compressive strength (UCS) and California Bearing Ratio (CBR) tests. Results showed decrease in Atterberg limits and increase in UCS and CBR. Summaya et al (2016) stabilized clay soil using tile waste which is ceramic in nature. 30% tile waste was observed to be the optimal mixture to give maximum UCS result of 80kN/m^2. Saini (2018) treated a clay of high plasticity with ceramic waste. Results revealed that liquid limit reduced from 68% to 47% with addition of 20% ceramic waste. The plastic limit also reduced from 31% to 25% with addition of 20% ceramic waste. The CBR increased from 2% to 4.1% while the swell pressure reduced from 104 to 54kN/m^2 with addition of 20% ceramic waste. Tile waste with sodium hydroxide was used to stabilized weak soil using index properties, CBR and direct shear tests as evaluation criteria (Neeladharan et al, 2017). The Atterberg limits were observed to reduce to between 25 to 35% tile waste after which the values increased again. The Maximum dry densities (MDD), shear stress and CBR values also increased to 35% tile waste after which the values reduced again.

Attempt have been made to stabilize fine sand with ceramic tiles waste for use as embankment material (Panwar and Ameta, 2016). The sand used in the research was passed through 4.75mm sieve and retained on 2.36mm sieve while the ceramic tile waste was added at 0, 2, 4, 6, 8 and 12% by weight of the dried soil. Results showed that the shear strength parameters and coefficient of permeability improved significantly. Recycled ceramic crushed tiles (RCT) of 0.3 and 1.18mm sizes were used to stabilized soft soil (Al-bared et al, 2018). Compaction test, UCS test, Scanning Electron Microscopy (SEM) test and Energy Dispersive Spectroscopy (EDS) were used as evaluation criteria. Results showed that the MDD increased from 1.59Mg/m^3 to 1.82 Mg/m^3 and 1.77 Mg/m^3 at addition of 40% 1.18mm sized RCT and 0.03mm sized RCT respectively. Whereas the UCS increased from 50kN/m^2 to 250 kN/m^2 and 225 kN/m^2 at addition of 40% 1.18mm sized RCT and 0.03mm sized RCT respectively. The optimal value of RCT required to treat soft soil was observed to be 10% and 40% for 1.18mm and 0.03mm sized RCT respectively.

Stabilization of shrink-swell soils using ceramic waste dust (CWD) was studied (Chen and Idusuyi, 2015). The author used free swell index, swell pressure, Atterberg limits, compaction characteristics, UCS and CBR as evaluation criteria to achieved the desired objective. The results showed that Atterberg limits, optimum moisture content (OMC), free swell, swell pressure decreased with increase in CWD while the MDD, UCS and CBR increased with increase in CWD. This study is intended to evaluate the effect of ceramic waste dust on the strength of cement stabilized black cotton soil using UCS as evaluation criteria. The aim of this research work is to determine the effects of Ceramic wastes on the Geotechnical Properties of Cement Stabilized Black Cotton Soil. The precise objectives are: Determined the index properties of the black cotton soil and micro structural properties of black cotton soil mixed with varied proportion of Ceramic waste dust the compaction characteristics of cement stabilized black cotton soil and black cotton soil mixed with varied proportion of Ceramic waste .Determined the unconfined compressive strength of cement stabilized black cotton soil and black cotton soil mixed with varied proportion of Ceramic waste.

2.0 Materials

The materials used for this research includes clay soil, cement, ceramic waste dust and distilled water. The black cotton soil was collected from Barkindo along Lamurde-Gombe road in Numan Local Government area of Gombe State, Nigeria. The clay soil was collected at depth of between 0.5m – 1.5m using the method of disturbed sampling. The clay soil was then air-dried and pulverized according to the method highlighted in part 1 of BS1377 (1992). The cement used was a Portland cement purchased locally in a commercial market and kept in a dried place to avoid moisturization of the cement. The ceramic waste dust used was a collection of waste tiles and ceramic plates which are crushed in to smaller particles and sieved through BS sieve 0.075mm. The distilled water was purchased from a medical shop opposite General Hospital, Minna, Niger State, Nigeria. These materials are shown in figure 1.

Figure 1: (a) Black cotton soil; (b) Waste ceramic dust; (c) Cement

2.1 **Methods**

The air-dried clay soil sample was characterized through the determination of its index properties in Civil Engineering Laboratory, Federal University of Technology, Minna, Nigeria, using the method highlighted in BS 1377 (1992). X-Ray Diffraction (XRD) and X-Ray fluorescence (XRF) tests were also carried out on the clay soil. The tests were conducted in Ithemba Laboratory, Somerset West, South Africa and Electron Microscope Unit, University of Western Cape, Cape Town, South Africa. Phase characterization of the minerals and estimate of the average crystallite size of the various synthesized materials were conducted on a Bruker AXS D8 XRD system.

Scanning Electron Microscopy (SEM) test was also carried out by placing 0.05 mg of the synthesized materials, sprinkled on a sample holder, covered with carbon adhesive tape and wire sputter coated with Au-Pd using Quorum T15OT for 5 minutes prior to analysis. The sputter coated samples were characterized using Zeiss Auriga HRSEM. The SEM, which visualizes morphology and microstructure of the synthesized products were analyzed using Zeiss Auriga HRSEM. This was carried out to determine the structure of the mineral particles contained in the clay. The clay was then mixed with 0, 2, 4 and 6% cement which in turn is mixed with 0, 10, 20, 30 and 40% waste ceramic dust () each as shown in table 1. The idea behind 40% maximum ceramic waste dust is derived from the CWD works of (Sabat, 2012; Sumayya et al, 2016; Neeladharan et al, 2017) whose optimal percentage of CWD used for soil stabilization ranges from 25% to 35%. The clay soil and clay mixed with varied proportions of cement and CWD were compacted at standard proctor compaction energy level to obtain the maximum dry density (MDD) and optimum moisture content (OMC) of the mixtures. The predetermined MDD and CMC were then used to prepared specimen for UCS test. The UCS specimen of 38mm diameter and 76mm height was molded at standard proctor compaction energy level. The specimen was wax-cured for 1, 7, 14, 28, 60 and 90 days before UCS test as shown in figure 2. The test was carried out in the department of civil engineering, Federal University of Technology Minna at the speed of 1.2mm/min.

Table1. Mixtures of cement and CWD

Cement (%)	Ceramic Waste Dust (%)
0	0
	10
	20
	30
	40
2	0
	10
	20
	30
	40
4	0
	10
	20
	30
	40
6	0
	10
	20
	30
	40

Figure 2 Unconfined compressive strength test

3.0 Results and Discussions

3.1 Index Properties Tests

The result of the index properties of the clay soil is shown on table 2 while the compaction characteristic graphs of the clay mixed with varied composition of CWD is presented in figure 3.

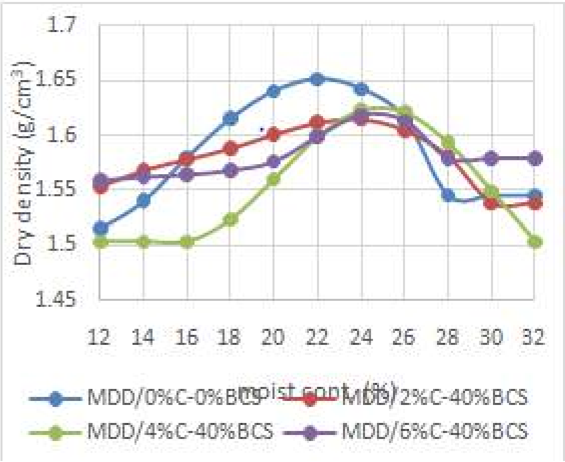


Figure 3: compaction characteristic with Varied CWD

Table 2 Summary of Index Properties of the clay

Description	**Quantity**
Percentage passing sieve 2.000mm	98.7
Percentage passing sieve 0.425mm	87.1
Percentage passing sieve 0.075mm	77.6
Liquid Limit	52.1

From table 2, the clay classified as A-7-6 according to AASHTO soil classification system and clay of high plasticity (CH) according to Unified Soil Classification System. From the index properties result, this clay cannot be used as material for road pavement structure and cannot also be used to support pavement structures. It therefore requires stabilization to improve its strength and durability. Figure 3 showed that MDD of the soil mixtures decreased with increase in cement and CWD while the OMC increased in the same order..

3.2 Microstructural Analysis of the Black Cotton Soil

The result of the microstructural analysis of the black cotton soil are shown from XRD, SEM and EDS results as shown in figures 4, 5 and 6.

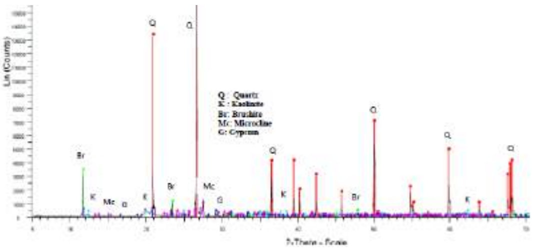


Figure 4 Graph of XRD Result

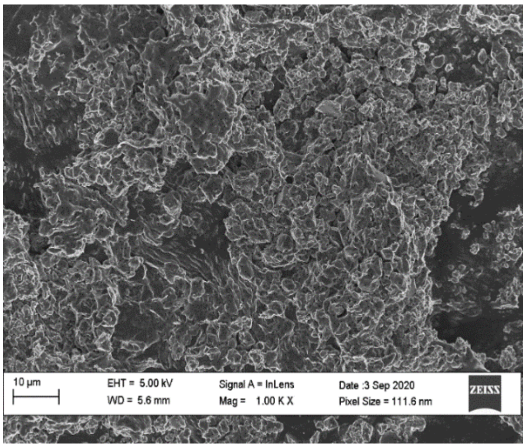


Figure 6: Result of EDS test

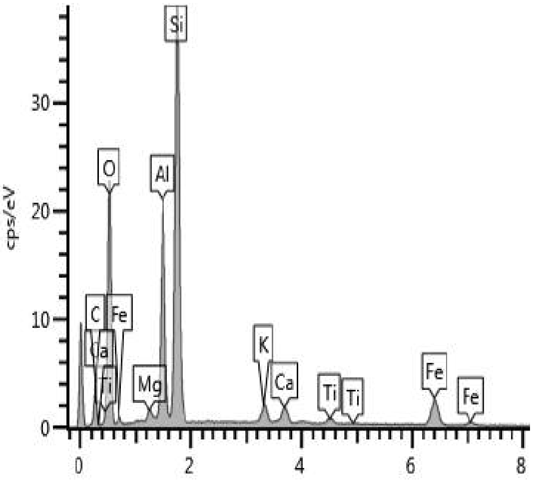


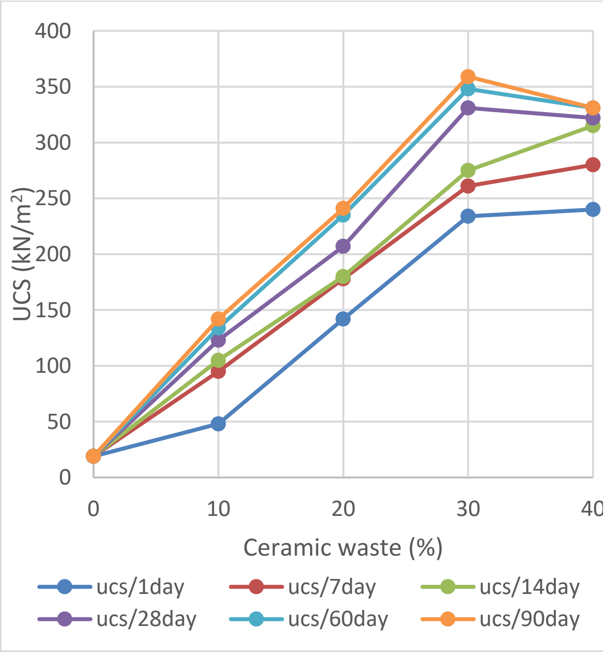
Figure 6: Result of EDS test

Result of Scanning Electron Microscopy (SEM) and Electron Dispersion Spectroscopy (EDS) are shown in Figures 5 and 6. The EDS result showed 22.6% carbon, 39.4% oxygen, 0.51% magnesium, 9.3% Aluminium, 19.4% silicon, 1.25% potassium, 1.31% calcium, 0.59% titanium and 5.7% iron. The silicon-aluminium ratio of 2.09 confirms the absence of montmorillonite mineral. The SEM image of the soil, remolded at standard Proctor compaction energy level (Figure 4), revealed aggregation of flaky particles with interconnected pore spaces. The aggregation is a dense fabric of flecky clay particles similar to those reported by Zang *et al*. (2013), Jaiswal and Lal (2016) and Abdullah *et al*. (2017).

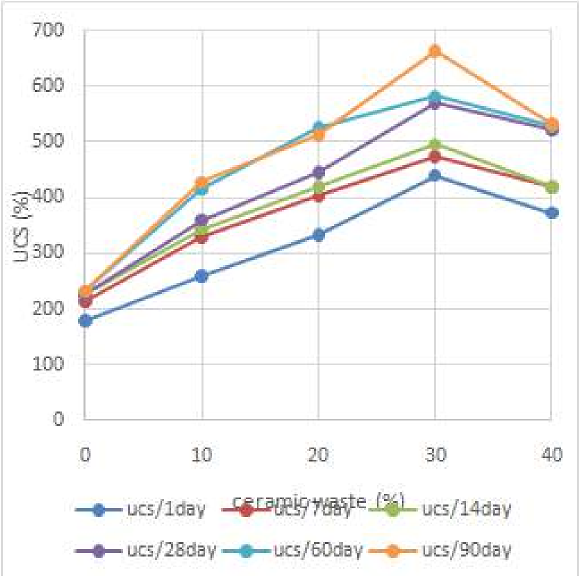
Figure 4 present result of xrd test on the clay soil. The result indicates the presence of substantial composition of minerals, including quartz, kaolinite, brushite, microcline and gypsum minerals. The absence of a peak at 8.96^0 also confirms the absence of montmorillonite mineral (sharma et al, 2012). These are both primary and secondary minerals. The mdd and omc of the clay soil, compacted at standard proctor energy level was observed to be 1.651 g/cm^3 and 22.3% respectively.

3.3 Effect of Ceramic Waste Dust on Cement Stabilized Black Clay soil

The effect of UCS with varied composition of CWD for 0, 2, 4 and 6 percentages of cement is shown in figures 7a, 7b, 7c and 7d respectively. Variation of UCS with varied percentage of CWD and 0% cement is shown in figure 7a. The result revealed continuous increase in UCS with increase in CWD.



(a)



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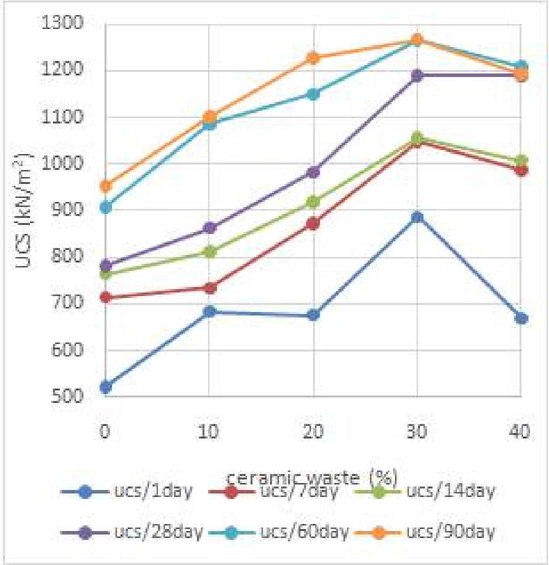

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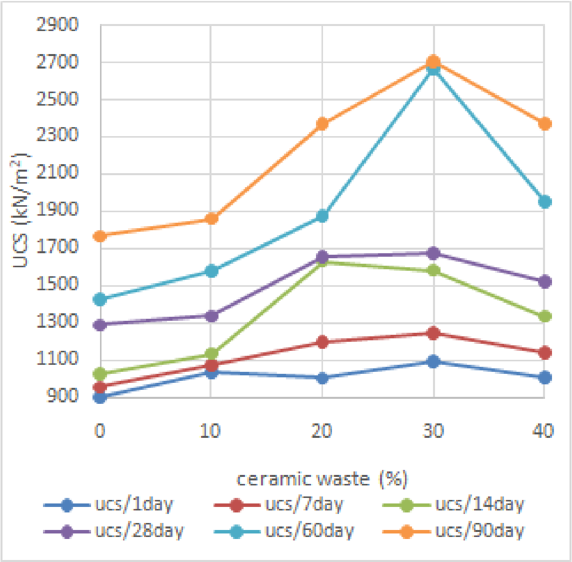


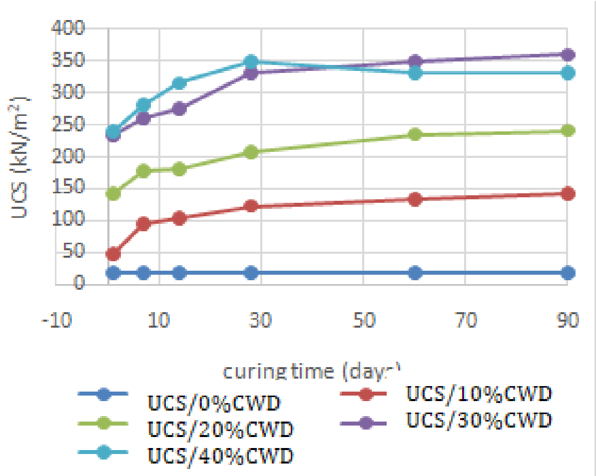
(d)

Figure 7: Variation of UCS with CWD for (a) 0% cement, (b) 2% cement, (c) 4% cement, (d) 6% cement.

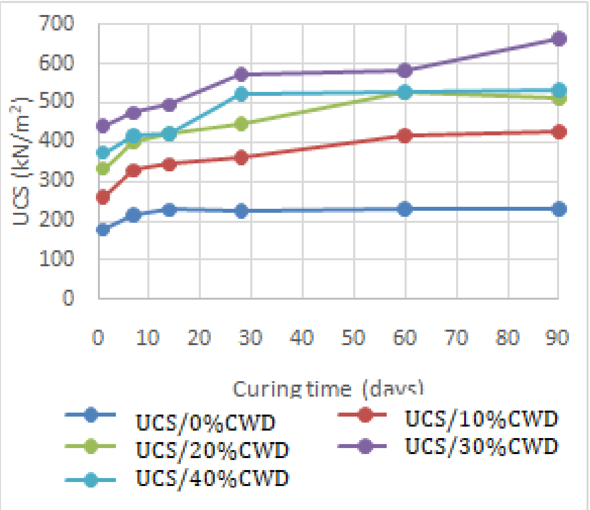
The values increased from 19kN/m^2 at 0% CWD to 48, 142, 234, and 240kN/m^2 at 10, 20, 30, and 40% CWD respectively. The UCS values increased from19 kN/m^2 at 0% cement and 0% CWD to 359kN/m^2 at 0% cement and 30% CWD after 90 days of curing which represents almost 19 times increase in strength of the black cotton soil. This UCS increase in the absence of cement is probably due to calcium based minerals like Brushite and gypsum. For 2% cement after 90 days of curing, the UCS values increased from 178kN/m^2 at 2% cement and 0% CWD within 1 day of curing to 664kN/m^2 at 2% cement and 30% CWD after 90 days of curing. This represents 3.7 times increase in UCS of the stabilized clay soil. Higher values of UCS were observed at 6% cement when mixed with varied composition of CWD. The UCS values increased from 903kN/m^2 at 6% cement and 0% CWD within 1 day of curing to maximum of 2703kN/m^2 at 6% cement and 30% CWD after 90 days of curing. This represents 3.0 times increase in UCS of the stabilized clay soil. This value is within the 2500 to 3000kN/m2 UCS value specified for stabilized materials to be used as base course for high trafficked road bases.

Effect of Curing Time on Cement and Ceramic Waste Dust Stabilization of Clay

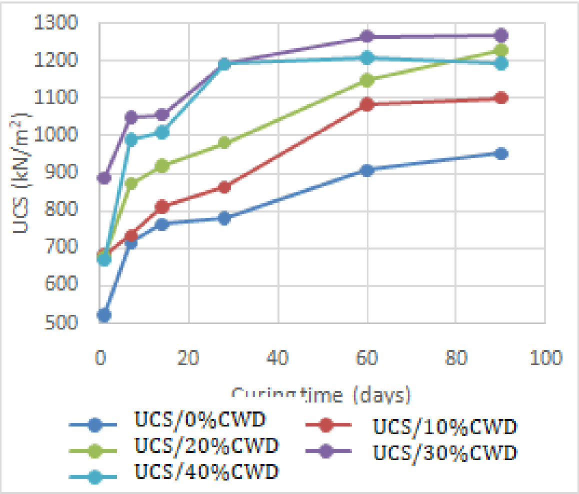
The variation of UCS values with curing days for varied composition of waste ceramic dust are shown in figures 8a-d.For 0, 2 and 4% cement, it is observed from the graphs that rate of strength gain is higher



(a)



(b)



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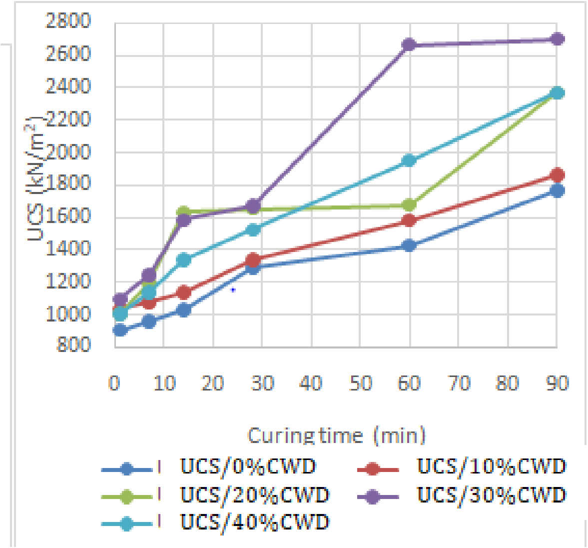

(d)

Figure 8: Variation of UCS with curing days for (a) 0% cement, (b) 2% cement, (c) 4% cement, (d) 6% cement

at between 0 to 28 days after which the rate became gentle. For 6% cement addition however, the rate of strength gain was observed to be averagely constant throughout the 90 days of curing. This is probably due to the reaction between the Pozzolanic waste ceramic dust and large amount of calcium hydroxide released as byproduct of the reaction of cement in the presence of water. At 0% cement addition, the trend in UCS with curing days for varied composition of CWD showed relatively constant increase in UCS between 0 – 10%, 10 – 20% and 20 - 30% CWD. However, the trend for 30 - 40% CWD with curing days were very close which is an indication that 30% CWD is the optimal CWD required for effective stabilization of clay soil in the absence of cement. For 2, 4 and 6% cement addition, the trend revealed that the trend of the mixture with 30% CWD is always above that with 40% CWD. These results showed that 30% CWD is still the optimal mixture to give the highest strength when used as admixture with cement.

4. Conclusions

The clay used in this study classified as A-7-6 and Clay of high plasticity (CH) based on AASHTO and Unified Soil Classification Systems respectively.

The major minerals contained in the clay includes Quartz, Kaolinite, Brushite, Microcline and Gypsum.

About 19 times increase in UCS strength was recorded on addition of 40% CWD to the clay soil in the absence of cement.

The increase in UCS strength with increase in composition of CWD and curing days in the presence of cement, confirm the Pozzolanic reaction between the

CWD and calcium hydroxide generated as byproduct from the reaction of cement on addition of water.

Maximum UCS strength of 2700kN/m recorded at 6% cement and 30% CWD is adequate for a soil material to be used as base course material for highly trafficked road bases.

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