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PREDICTING THE COMPRESSIVE STRENGTH OF OBUDU EARTH BLOCKS STABILIZED WITH CEMENT KILN DUST

F.O. Okafor[a], **D.E. Ewa**[b]

[a]Department of Civil Engineering, University of Nigeria Nsukka, Nigeria. ***Email:*** *fidelis.okafor@unn.edu.ng*
[b]Department of Civil Engineering, Cross River University of Technology, Calabar, Nigeria.
Email: *eldad4sky@yahoo.com*

Abstract

The study investigates the effect of Cement Kiln Dust (CKD) on the Compressive Strength of Obudu Earth Blocks. The soil used for the blocks was classified as A -7-6 (0) or CH. CKD content of up to 20% by weight of the dry soil was used to evaluate the Compressive strength of the blocks at 12%, 16% and 20% water content by dry weight of the CKD-Soil matrix. 150 mm x 150 mm stabilized cubes moulded at various CKD and water content were cured and crushed at 7, 14, and 28 days. The study found that the compressive strength of CKD-soil block was about twice and half higher than that of the unstabilized block, and exceeded the minimum strength of 2.0 N/mm^2 recommended by "ASTMD1633-00" or 2.8 N/mm^2 of "BS 6073". The Compressive strength of the earth blocks generally increased with increase in CKD content and curing period. The curing condition was also found to affect the strength of CKD-earth blocks, and 35% reduction in strength was observed with direct sun light curing. Scheffe's optimization models were used to predict the compressive strengths of the CKD-soil blocks at varying proportions of CKD. It was concluded that CKD can be used as a good stabilizing agent for the Obudu earth blocks.

Keywords: Obudu earth blocks, cement kiln dust (CKD), compressive strength

1. Introduction

The potential of local and cheap earth blocks as material for construction in Nigeria has not been optimally utilized. This has made the dream of house ownership for most people an illusion. The commonest and most popular walling unit is the sandcrete block. The most essential constituent of sandcrete is cement; incidentally, this is also the most expensive component. To minimize cost and maximize profit, producers of these blocks in Nigeria reduce the quantity of cement needed to give acceptable quality of sandcrete blocks, leading to the flooding of low-strength blocks in the commercial market. For instance, Abdullahi [1] found that the commercial sandcrete blocks in Minna, Nigeria, were below the 3.5 N/mm^2 standards recommended by The Nigerian Industrial Standard, (NIS 87: 2000) [2].

Cement kiln dust has proved to be a good soil stabilizer for expansive clays, Sulapha and Jan [3] and Zaki [4]. In the works of Zaman et al [5], results similar to Portland cement, fly ash and lime stabilization were obtained using cement kiln dust for soil stabilization. Cement kiln dust and fly ash were used to stabilize base courses in road construction in the form of a pozzolanic non-cement concrete with lime stone as aggregate as reported by Miller et al [6], the mixes were found to possess autogenous healing characteristics on the base course. McCoy [7] reported that cement kiln dust with low Loss On Ignition (LOI) values showed improvement in the unconfined compressive strengths of clays and reduced the plasticity index. Bhatty et al [8] on the other hand, reported that adding cement kiln dust with high LOI values results in relatively lower unconfined compressive strengths and higher plasticity indices. From the laboratory and field tests data conducted by Miller and Zaman [9] where CKD was used as an alternative to quick lime for subgrade stabilization, it was concluded that CKD was more effective than quick lime. It was also cost effective and required less construction time than treatment with quick lime. The test also showed that the LOI content was an important factor in the effectiveness of CKD. High LOI implies a higher percentage of bound water within its chemical structure and less CaO available to react.

The properties of hollow sandcrete blocks with cement kiln dust as a Portland cement replacement material and as an additive were investigated by Udoeyo and Ridnap [10], and it was reported that when cement kiln dust was used as a cement replacement material, the compressive strength and the density of the blocks generally decreased with higher replacement levels of ordinary Portland cement by cement kiln dust, while the percentage water absorption of the blocks increased with higher replacement levels. On the other hand, when cement kiln dust was used as an additive, within the investigated levels, an improvement in the compressive strength of up to 54% was observed. The density of the blocks also increased with higher cement kiln dust content as additive, while the percentage water absorption of blocks showed a reverse trend.

Obudu earth blocks account for the shelter of many rural families in Obudu and is a cheaper alternative to sandcrete blocks. However, the average compressive strength of the of the Obudu earth blocks was found to fall below the specification of 2.0 N/mm^2 of ASTMD1633-00 [11]. The unstabilized blocks from random sampling had an average compressive strength of 1.24 N/mm^2; this is lower than the 2 N/mm^2 requirements by ASTMD1633-00 [11]. The objective of this research work is to investigate the possibility of improving the compressive strength of the Obudu earth block using cement kiln dust (CKD) as a stabilizing agent.

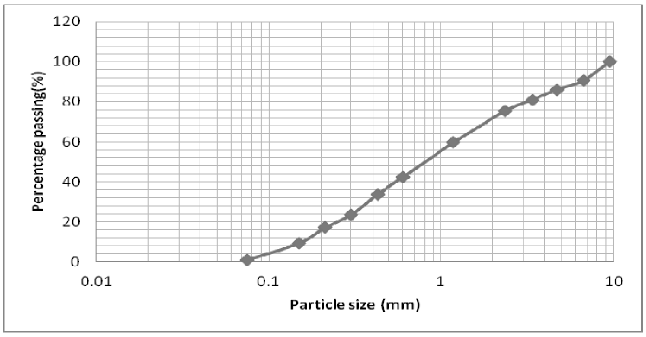


Figure 1: Particle size distribution curve for the Obudu soil.

Table 1: Index properties of Obudu soil.

DESCRIPTION	RESULTS
Liquid Limit (%)	50.0
Plastic Limit (%)	16.8
Plasticity Index (%)	33.2
Percentage Passing BS Sieve 200 (0.075mm)	1.18
Uniformity Coefficient	7.6
Coefficient of Curvature	1.03
AASHTO Classification	A -7-6 (0)
USCS Classification	CH
Maximum Dry Density (kg/m^3)	1732
Optimum Moisture Content (%)	12.0
California Bearing Ratio (after 24 hrs soaking)	-
Specific Gravity	2.55
Colour	Reddish Grey

2. Materials and Methods

The soil used for this research work was sampled by method of disturbed sampling from an earth block moulding site in Obudu and classified as A-7-6(0) or CH. Obudu is located at (longitude 09° 10′ 06″ E, latitude 06° 40′ 22″ N). Cement kiln dust (CKD) used was obtained from United Cement Factory Kiln, Calabar, all in Cross River State, Nigeria. The soil collected was air dried in the open air and sieved through a 212 μmm sieve before it was used for block moulding. The cement kiln dust was obtained in bags and stored in the workshop in air tight containers.

The index properties of the soil were determined in accordance with BS1377 [12] and are presented in Table 1. The results showed that the soil had liquid limits and plasticity index of 50% and 33.2% respectively and classified as Clay of high plasticity from the Casagrande Classification Chart, A-6-7(0) under the AASHTO classification. The specific gravity was 2.55 with a maximum dry density of 1732 kg/m^3 at an optimum moisture content of 12.0%.

The high plasticity nature of the soil makes it self-binding and blocks can be made from it even without stabilization. The particle size distribution curve of Figure 1 revealed that the aggregate fraction of the soil is well graded. With uniformity coefficient (Cu) and coefficient of curvature (Cc) of 7.6 and 1.13 respectively.

The characteristics of the Cement Kiln Dust used are presented in the chemical analysis of Table 2. The dust has a low loss on Ignition value of 4.38. The specific gravity of the dust was found to be 2.60.

Earth blocks cubes of 150 mm × 150 mm × 150 mm were moulded and first cured by covering with a damp material after setting must have taken place. This provided the right humidity within the blocks to eliminate loss of moisture needed for hydration to continue. The blocks were shaded from direct sunlight for three days. The coverings were removed and curing continued by allowing the blocks under shed until the various crushing dates.

3. Results and Discussion

3.1. Specific gravity, density of CKD and soil

The specific gravity of the CKD was found to be 2.60, this value is lower than 2.95 reported by Robert et al [13] but higher than 1.90 reported by Moses et al [14]. The reason for the results and trend may be due to the variability of CKD whose characteristics

Table 2: Chemical composition of cement kiln dust.

Constituent	SiO_2	Al_2O	CaO	MgO	SO_3	K_2O	Na_2O	Cl	LOI	Free CaO
% Composition	14.79	4.51	57.39	2.66	10.48	1.26	0.18	0.31	4.38	4.04

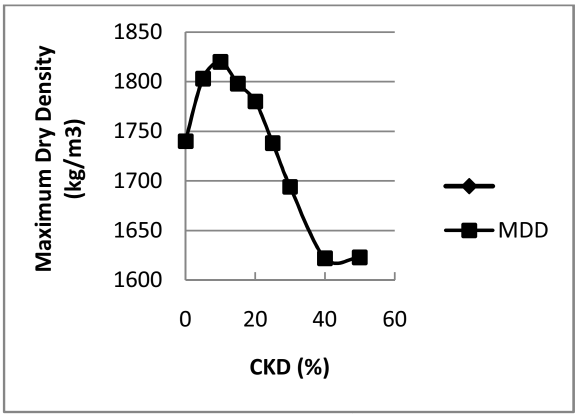


Figure 2: Effect of CKD on MDD.

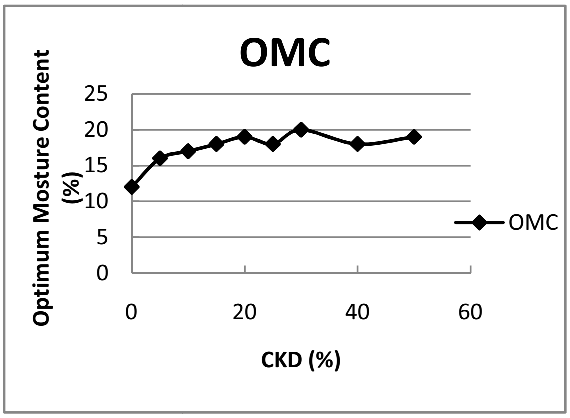


Figure 3: Effect of CKD on OMC.

are dependent on the raw materials, fuels, kiln pyroprocessing type, overall equipment layout, and type of cement being manufactured, Maslehuddin et al [15]. The loose and compacted densities of the CKD were found to be 1495 kg/m^3 and 1600 kg/m^3 respectively. These are higher than the values for Rice Husk Ash (RHA) as reported by Oyetola [16], signifying that CKD is heavier than RHA. The specific gravity values for the soil were found to be 2.55 as with most soils with high plasticity. The uncompacted and compacted densities of the soil were 1450 kg/m^3 and 1580 kg/m^3 respectively. The CKD appears heavier than the soil used for the blocks.

3.2. Compaction Tests Results

The result of the effect of CKD on the compaction characteristics of the soil used for the blocks is presented in Figure 2. CKD stabilized soil showed an increase in maximum dry density (MDD).The maximum dry density (MDD) increased from 1732 kg/m^3 at 0% CKD to 1820 kg/m^3 at 10% CKD. The increase in MDD may be due to the improved bonding of particles of CKD with the soil giving a better void reduction and hence increased in compaction. It may also be inferred that the heavier specific gravity of the CKD used made the density to improve. This result agrees with the work of Zaki [4].

However, beyond 10% CKD, the MDD did not increase with increase in CKD content. This may be due to the fact that CKD can cause soil to become more brittle and is one of the drawbacks to the use of CKD for soil stabilization [17]. Traditionally, the optimum moisture requirement increased due to the cementing nature of CKD. Figure 3 shows the effect of CKD on OMC. As more CKD is added more water is needed to coat the surface area and lubricate the entire matrix for hydration process, Eze-Uzomaka et al [18].

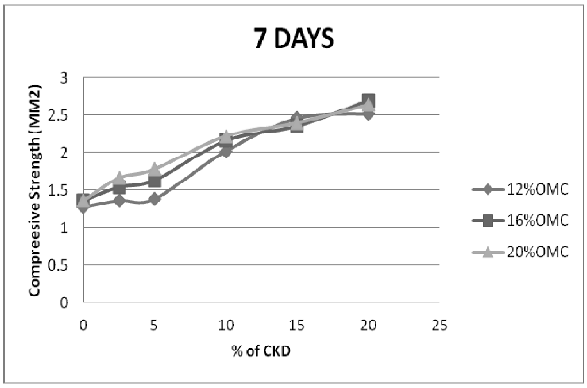


Figure 4: 7 Day Compressive Strength.

3.3. Compressive strength test results

Results for the compressive strength test on the stabilized earth blocks specimens are presented in Figures 4 - 5. There was a general increase in the compressive strength of the stabilized blocks with increased in CKD content, curing period, and percentage of moisture used.

The hydration of CKD releases calcium silicate hydrate (C-S-H), monosulphoaluminates, (C_4ASH_{12}) and calcium hydroxides, $Ca(OH)_2$. The initial strengthening of the blocks is thought to be due to C-H-S and C_4ASH_{12} which are cementitious and have high binding capacity. They interlock and surround the coarse aggregates fraction and create a strong network within the matrix giving rigidity to the composite block structure [19].

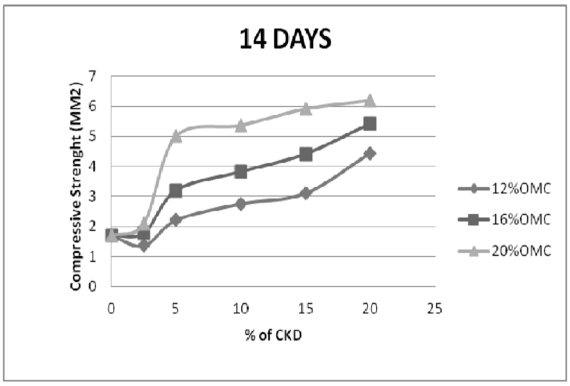


Figure 5: 14 Day Compressive Strength.

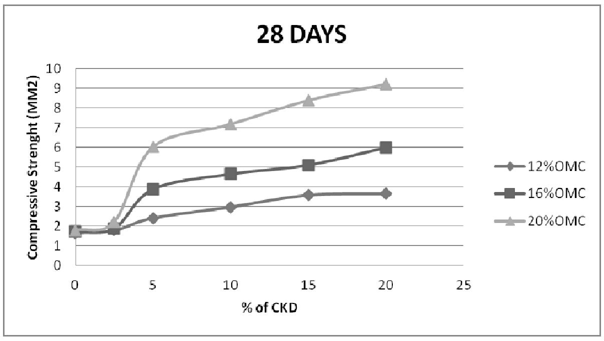
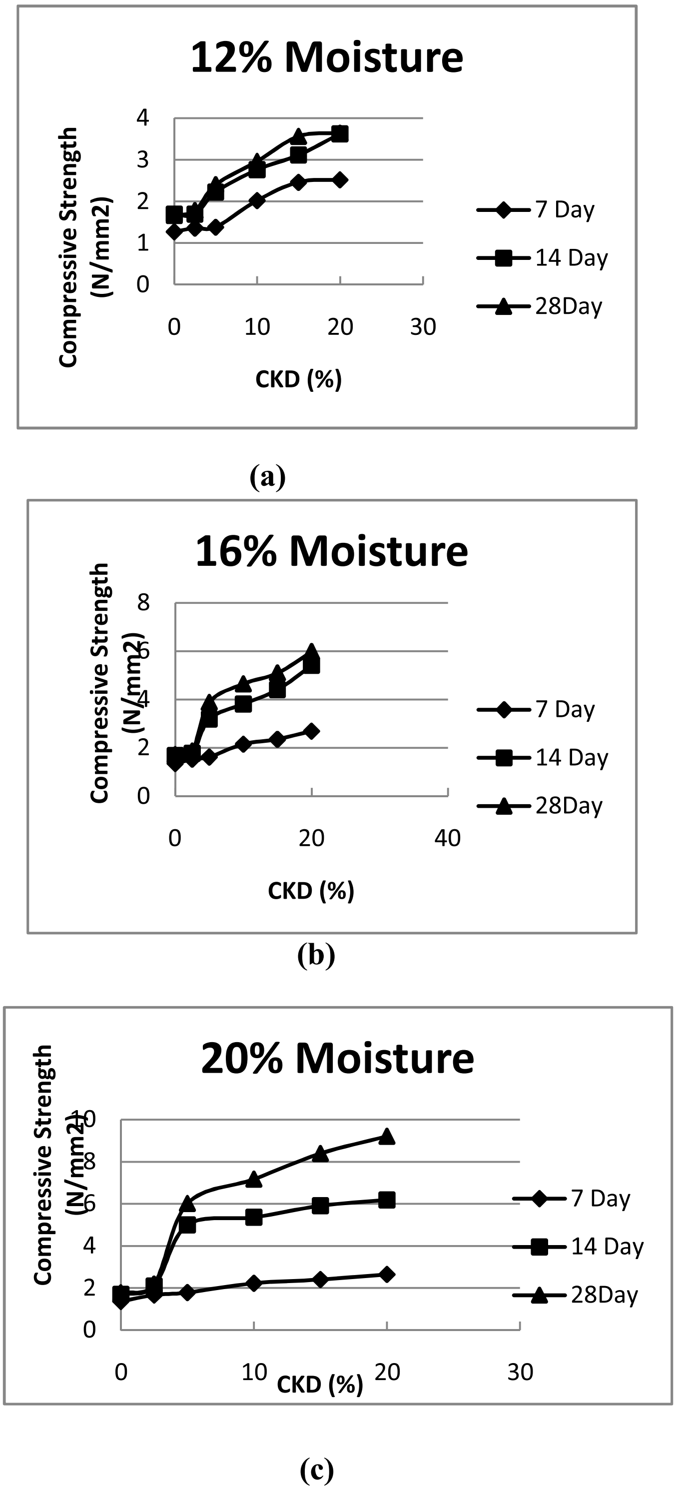


Figure 6: 28 Day Compressive Strength.

The calcium hydroxide released during primary stabilization also reacts with the silicates in the soil to form calcium silicate hydrate (C-S-H) and calcium aluminates hydrates (C-A-H). This pozzolanic reaction with its gelatinous hydrates also contributes to the strengthening of the blocks and this stabilizing effect also agrees with the works of Sulapha and Jan [3].

3.4. Effect of CKD contents on the compressive strength

The strength of the CKD stabilized soil block increased with increase in the cement kiln dust content. This is due to the ability of the hydrates to coat a high proportion of the coarse aggregates fraction of the soil and filling of the voids spaces between particles, making the matrix denser. The block specimens with lower CKD content imply a block with higher voids content. High voids are an indication of high porosity block with weak strength. Another implication with low CKD content is that the large proportion of unstabilized soil remains present in the block with little contribution to strength.



(a)

(b)

(c)

Figure 7: (a-c): Effect of Curing Period on Compressive Strength of CKD Stabilized Blocks.

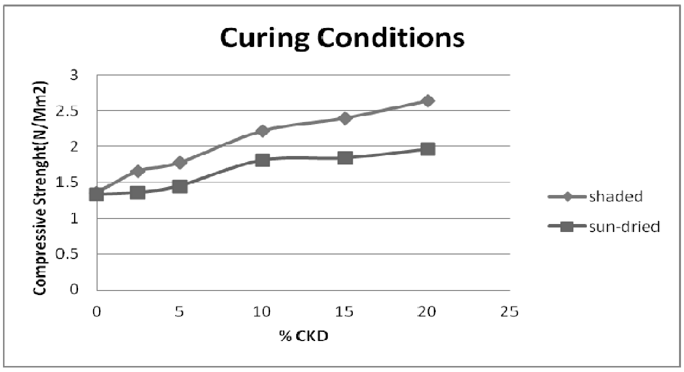


Figure 8: Effects of curing conditions on strength of blocks.

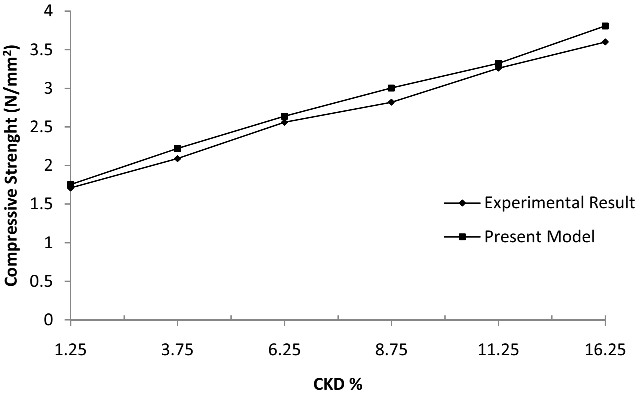


Figure 9: Relationship between compressive strength and CKD at 12% moisture content.

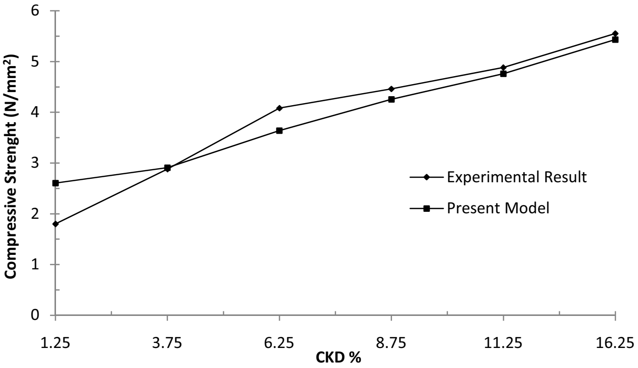


Figure 10: Relationship between compressive strength and CKD at 16% moisture content.

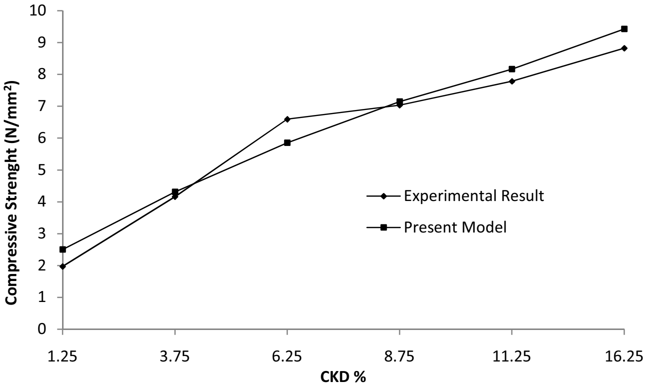


Figure 11: Relationship between compressive strength and CKD at 20% moisture content.

3.5. Effect of moisture percentage on compressive strengths

The amount of water to be used in stabilized earth blocks units is still receiving research attention [19]. The amount of water used for this study was governed by the range of optimum moisture contents from the CKD effect on compaction. Three water percentages of 12, 16, and 20 of the total dry weight of the CKD Soil matrix at each level were used. The test results from Figures 4, 5 and 6, indicated that the compressive strength increased with increase in water content used, the highest being 20%. This is attributed to the fact that hydration is achieved with more water content. The lower ranges of 12% and 16% could not give enough moisture for this hardening to progress. Therefore the insufficient percentage of water resulted in weaker blocks, although their strengths at 10% met with the minimum standards of 2 N/mm^2 for adobe blocks or 2.8 N/mm^2 of sandcrete blocks after 28 days.

3.6. Effect of curing period on compressive strength

The result of Figure 7 (a-c) showed that the CKD stabilized blocks increased in compressive strength with age at curing, with greater strength at 28 days of curing. Being a Portland cement bye product, the hardening of CKD is time bound and also is the strength development of CKD blocks. In the presence of moisture, the hydration is uninterrupted and continues almost indefinitely ensuring better strength of blocks. BS12 [20] recommends a maximum curing duration of 28 days for cement hydration.

3.7. Effects of curing conditions on compressive strength

The results of the 7 Day compressive strength of sun-dried CKD stabilized blocks and the 7 Day compressive strength of the blocks cured in a shed at 20% moisture are presented in Figure 8. The results showed higher strengths for the blocks shielded from direct sun light during curing period. The open air or sun-dried blocks gave lower strengths due to the apparent loss in moisture needed for hydration and strength development of the CKD stabilized blocks.

4. Modeling Compressive Strengths

Scheffe's [21] predictive mixture models were formulated for the 28 Day compressive strength at various water contents. The correlation between the experimental and the model results were computed for **r** = ± 1 and the **t**-test was used to verify the significance of **r** at 5% level at four degree of freedom. Figures 9-11 show the plots of the experimental and predictive models. The three models corresponding to 12%, 16% and, 20% water content respectively are:

$$\sigma = -0.178x_1 + 0.015x_2 + 0.004x_1x_2,\ r = 0.998 \quad (1)$$

$t_{0.025}$ at 4 degree of freedom = 2.78, (from distribution table) $t_{calculated} = 31.58$

$$\sigma = -0.502x_1 + 0.016x_2 + 0.009x_1x_2,\ r = 0.86 \quad (2)$$

$t_{0.025}$ at 4 degree of freedom = 2.78,(from distribution table) $t_{calculated} = 3.37$

$$\sigma = -1.256x_1 + 0.015x_2 + 0.021x_1x_2,\ r = 0.80 \quad (3)$$

$t_{0.025}$ at 4 degree of freedom = 2.78, (from distribution table) $t_{calculated} = 2.70$

Where, σ = compressive strength, x_1 = % CKD and x_2 = % of soil.

From the above, the experimental and model results are significantly correlated since the $t_{calculated}$ for Equations (1) and (2) were higher than the **t**-value from distribution Table. We therefore reject the null hypothesis. Equation 1 with the highest **r**-value of 0.99 is a good predicting model of the compressive strength of the Obudu earth blocks as shown in Figure 9 with the results plots closely parallel. Equations (2) and (3) have **r**-values of 0.86 and 0.80 respectively and from Figures 10 and 11 both the experimental and model plots agree at some points. However, Equation 3 did not pass the significance test, and therefore, may not be a good predictive model.

5. Conclusion

The following conclusions can be drawn from the study.

1. The study found that the average compressive strength of unstabilized Obudu earth blocks was 1.71 N/mm^2.
2. The compressive strength of the CKD stabilized earth block increased with increase in the cement kiln dust content, water content and with age at curing.
3. The test results indicate that with a range of 3.75 - 5.0% CKD content and moisture content range of 16 - 20%, the average 28 Day strength of 4.23 N/mm^2 exceeded the minimum strength of 2.0 N/mm^2 recommended by ATMD1633-00.
4. Scheffe's predictive models were found to predict reasonably the relation between the compressive strength as dependent variable and the percentage of CKD and soil.

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