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Predicting the Unconfined Compressive Strength of Laterite-Cement Mixture Obtained from Zaria at Different Water-Cement Ratio

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Abstract: *This study was carried out to predict the unconfined compressive strength (UCS) of cement treated laterite soil using the ratio of water content, (Mc) and cement content, (Cc). The laterite soil samples which were obtained from Zaria in Northern Nigeria were molded with predetermined water content and treated with cement slurry. The total water content of the laterite-cement mixture was varied from the liquid limit to three times the liquid limit of the soil. The cement content used was in increment of 3, 6, 9, and 12%. The prepared samples were cured for 7, 14, and 28 days and then tested for UCS. The result shows that moisture content, cement content, curing period as well as Mc/Cc affects the UCS development of the cement treated laterite soil. UCS decreased with increasing Mc to a value of 235 kN/m^2 when Mc was 2.0LL. At 12% cement content and 28 days curing period, a peak UCS value of 1675 kN/m^2 was achieved. From regression analysis result, it was found that the relationship between UCS and Mc/Cc could be represented by power function with constants obtained for each curing periods. The regression model developed was used to predict the UCS of the mixture from Mc/Cc. The predicted values were compared with measured laboratory values and it was found out that the difference was generally less than 10% on the average. These results suggest that Mc/Cc can be used to predict the UCS of cement treated laterite soil obtained from Zaria in Nigeria.*

Key words: Laterite soil; cement content; unconfined compressive strength; water content; water-cement ratio.

1. INTRODUCTION

Lateritic soils are the major and most commonly used soils in the construction of many civil engineering structures such as highway embankment, earth dams, runways and foundations in northern Nigeria. This is because they are naturally abundant in these parts of the world and therefore cost effective in construction applications.

However, unlike most soils, laterite soil is known to exhibit significantly different geotechnical characteristics depending on their genesis, climatic conditions and topography among other factors. The problem associated with its identification and its geotechnical characteristics have been reported, [1].

The wide range of utilization of laterite soil in pavement construction, for example, is due to the fact that some lateritic soils are known to make good materials for sub-base and base construction because of their natural stable grading with a suitable proportion of clayey material to act as binders [2]. This however cannot be said of most lateritic soil encounter in engineering project as they usually failed to meet the general engineering criteria for their intended use. Therefore, chemical treatment using additives such as cement and lime have been widely employed to improve the poor engineering properties of the soils, [3, 4, 5].

In cement stabilization of soils, water content, *Mc*, cement content, *Cc*, and curing period are reportedly among the major factors that determined the unconfined compressive strength, UCS, development of the stabilized soil, [5-11]. It was shown that higher cement dosage leads to higher strength gain. Also water content and longer curing period is required for complete hydration as well as pozzolanic reactions resulting in higher strength gain of the soil-cement mixture.

Study by [8, 12, 13, 14], have shown that water-cement ratio can be used to analyse and assess the laboratory strength development of cement admixed clay. They reported that based on water-cement ratio and Abrams's law, [15], the strength development of a given cement admixed clay is dependent only on the water-cement ratio, where the clay water content reflects the micro-fabric of the soft clay, while the cement content influences the level of bonding of the fabric,[13, 11].

In this study, the ratio of water content and cement content (*Mc/Cc*) was used to assess the UCS development of cement stabilized laterite soil obtained from Zaria in Northern Nigeria. From the data obtained, attempt was made to develop regression models that could possibly be used to predict strength values of the cement stabilized laterite soil using *Mc/Cc*.

2. MATERIALS AND METHODS

2.1 Materials

The soil used in this study was a natural reddish-brown laterite which was collected from a borrow pit along Shika road, Sabon Gari Local Government Area, Kaduna State in Northern Nigeria, (latitude 11° 15' N and longitude 7° 45' E), using the method of disturbed sampling.
Cement was Dangote cement product obtained from a major distributor in Samaru, Zaria, Nigeria.

2.2 Methods

2.2.1 Index properties of the laterite soil and oxide composition of cement

The laboratory tests to determine the index properties of the natural laterite soil were carried out in accordance with [16]. The results are shown in Table 1.
The oxide composition of the cement was determined at the Center for Energy Research and Training (CERT), A. B. U. Zaria, using the method of Energy Dispersive X-Ray Fluorescence (EDXRF). The oxide composition is shown in Table 2.

Table 1: Basic properties of Soil Sample

Properties	Quantity
Natural Moisture Content, (%)	5.8
Liquid Limit, (%)	31
Plastic Limit, (%)	11
Plasticity Index, (%)	20
Percentage Passing BS.No.200 sieve	52
Specific gravity	2.63
AASHTO classification	A-7-6
USCS Classification	CL
MDD (Mg/m^3)	1.70
OMC (%)	18.00
pH Value	6.7
Colour	Reddish Brown
Dominant Clay mineral	Kaolinite

Table 2: Oxide composition of cement

Oxide Composition	CaO	SiO_2	Al_2O_3	Fe_2O_3	Mn_2O_3	K_2O	Na_2O	TiO_2	LOI
Quantity (%)	66.07	20.2	6.14	2.25	-	0.72	-	-	1.14

2.2.2 Preparation of cement treated laterite and testing of specimen

The laterite soil samples were molded using a predetermined water content. The molded soil samples were mixed with cement slurry giving cement content of 3, 6, 9 and 12% respectively. Mixing was done until a homogeneous laterite-cement paste was obtained. The total water content of the mixture after addition of the cement slurry varies from the liquid limit, *LL*, up to three times liquid limit.
The use of high molding water content was to simulate the condition of soft clay at high water content, and condition of soil-cement column installation using the deep mixing method [11, 17].

The UCS specimen were prepared by pushing the soil-cement paste into cylindrical poly vinyl chloride (PVC) mold of 38mm diameter by 76mm height. The paste was pushed into the mold in three layers while tamping of the mold was carefully done after each layer of the paste in order to eliminate voids. The mold together with the specimen were sealed in a double layer polythene bags to prevent loss of moisture and the samples were cured inside a humidity room having a maintained ambient temperature of 25°C and 100% relative humidity until after each curing period of 7, 14, and 28 days respectively. After-curing, the specimen was removed from the molds and were subjected to testing for unconfined compressive strength, UCS.

3. DISCUSSION OF RESULTS

3.1 Preliminary results and soil classification

The particle size distribution of the natural soil as determine from dry sieving is shown in Figure 1 and the index properties of the natural soil are summarized in Table 1. From the combine results of the liquid limit, plasticity index and the particle size analysis, the soil was classified as A-7-6 and CL in accordance with AASHTO and the Unified Soil Classification System (USCS) respectively.

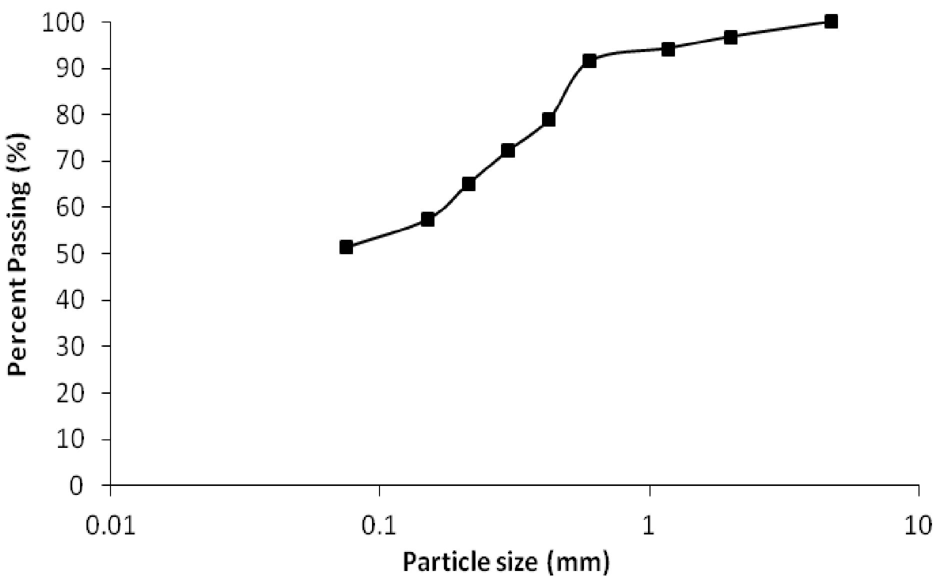

Fig. 1: Particle size distribution of laterite soil

3.2 Effect of cement content, molding water content and curing period on UCS

Figure 2, 3 and 4 shows the effect of cement content, *Cc*, molding water content, *Mc* and curing periods on the UCS of the stabilized laterite soil. In Figure 2, the UCS of the cement admixed laterite soil increased with increase *Cc* at all molding water contents and curing periods. This result is expected as increasing *Cc* translates to having more amounts of cement available for hydration reaction which produces the cementitious product of calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) responsible for strength gain. The strength was observed to increase from 343 to 1201kN/m^2 when cement content was varied from 3 to 12% at 7 days curing and molding water content equivalent to the *LL*. A peak value of 1675 kNm^2 was attained at 28 days curing and 12% cement content. This peak value however decreased with increasing *Mc*. When *Mc* increased from 1.5 to 2.0 of the *LL*, the peak UCS values at 28 days curing were 625 and 235kN/m^2 which was 2- and 5-times reduction in the strength values.

Further analysis of the effect of molding water content on the UCS can be seen in Figure 3. It can be clearly seen that as the water content increased, the UCS decreased at all curing age and *Cc*. This effect was observed and reported by [11, 18, 19].

For a given *Cc*, increased *Mc* results in increasing *Cc*/*Mc* which defines the cement to cement particle spacing. The high-water content may have led to a wider separation of the cement to cement and soil to cement particles spacing leading to a poor reaction and formation of weak cement bonding. This may have resulted in the low UCS development of the laterite cement mixture at high water content. Thus, higher strength gain was recorded at *Mc* around the *LL* while strength decreased as *Mc* increased. The *LL* appears to be the moisture content at which the right cement to cement as well as cement to soil particle spacing and orientation for completely effective hydration reaction was achieved leading to strong bonding and strength of the soil-cement mixture.

Figure 4 shows the variation of UCS with curing period. UCS increased with increasing curing period at all *Cc* and *Mc*. The increase in UCS development with curing period may be attributed to the effect of both immediate hydration reaction and long term pozzolanic reaction between cement and soil mineral. The immediate reaction results in the formation of (CSH) and (CAH) which is responsible for initial strength development. The pozzolanic reaction results when the bases from the cement compound and armorphous materials on the surface of the clay particles interact with silica and alumina leading to their dissolution. The dissolved hydrated silica and alumina gradually react with the calcium ion liberated from the hydrolysis of cement to form a new insoluble compound which hardens when cured which may be considered as secondary strength gain, [11]. Under favorable conditions, this reaction continues with time producing more cementing materials resulting in a stronger soil-cement matrix. This strength gain was observed at all *Cc* and *Mc*. The strength development is however considerable pronounced at *Mc* around the *LL* while it diminished at higher *Mc*.

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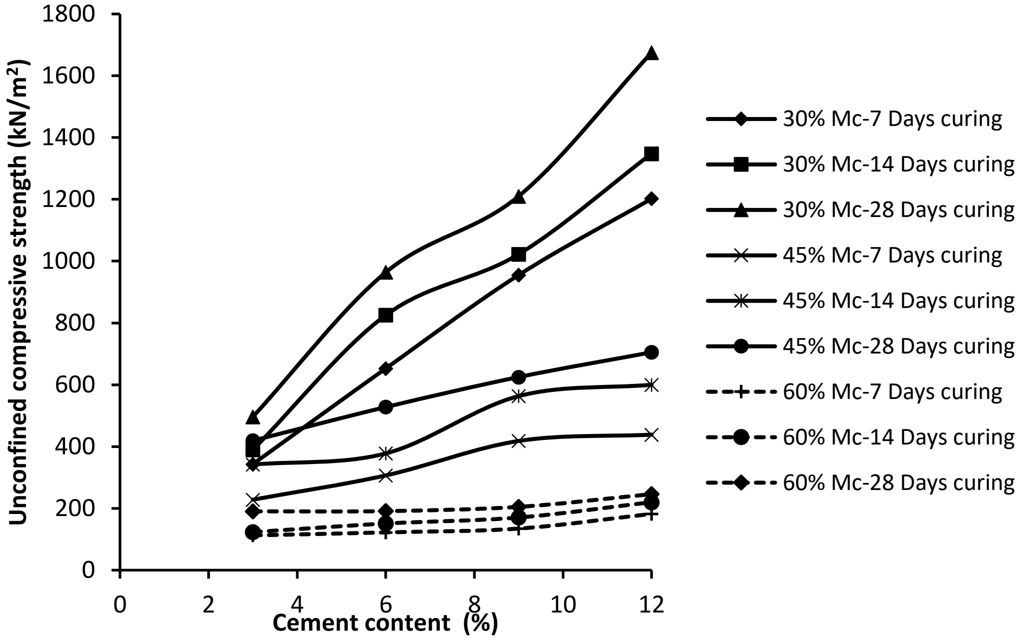

Fig. 2: Variation of UCS with cement content at varying molding water content and curing periods

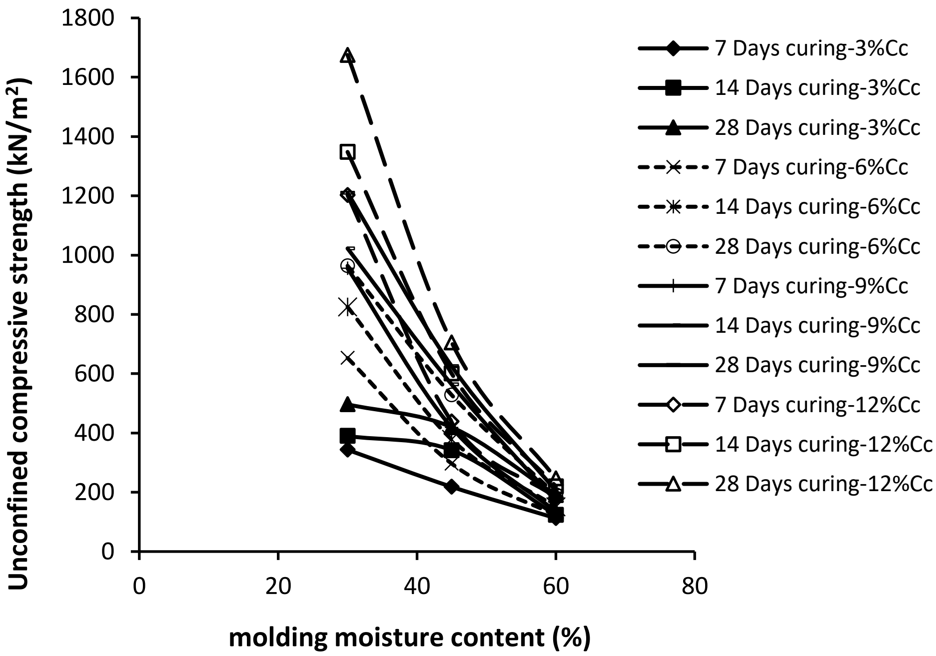

Fig. 3: Variation of UCS with molding water content at varying curing days and cement content

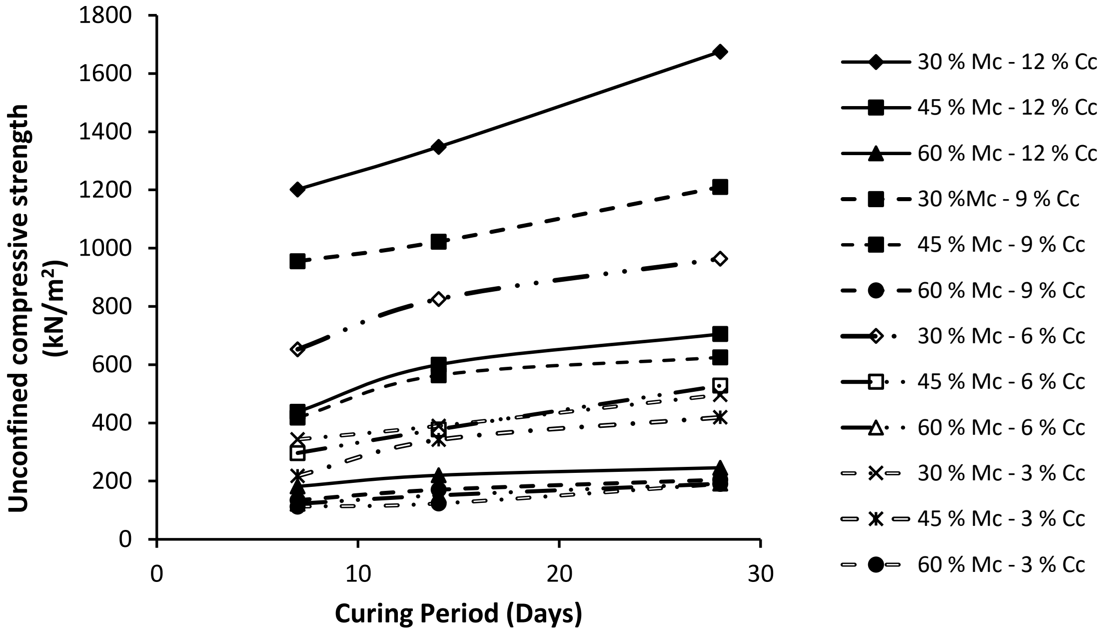

Fig. 4: Variation of UCS with curing periods at varying remolding water content (Mc) and cement content, (Cc)

3.3 Effect of the *Mc/Cc* on UCS

The effect of ***Mc/Cc*** on UCS can be observe in Figure 5. Generally, UCS decreased as ***Mc/Cc*** increased for all curing age and *Cc*. This result is in agreement with reports from other studies [8, 13, 19, 20]. ***Mc/Cc*** is known to influence cement-cement particle distance which in turn affect the hydration reactions of cement. Thus at high Mc/Cc, the cement to cement particle distance are wider apart leading to weak reaction and bonding and hence weak strength development of the soil cement mixture. The opposie can be said to happen when Mc/Cc is low. This may have explain the trend observed in Fig 5 which showed a reasonable relation between UCS and the ratio *Mc/Cc* at the different curing periods.

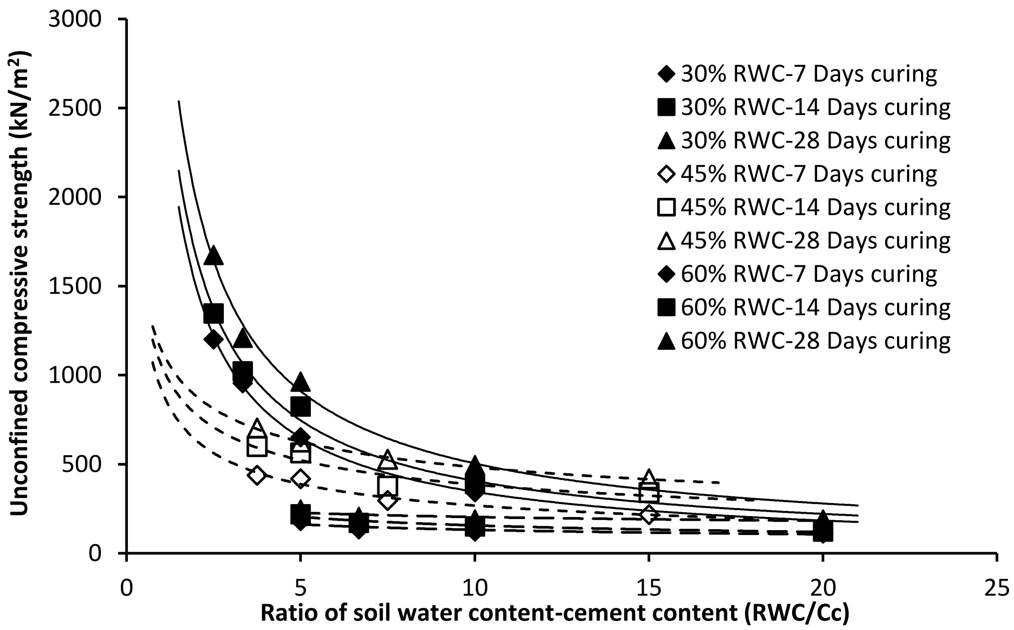

Fig. 5: Variation of UCS with curing periods at varying remolding water content (Mc) and cement content, (Cc)

3.4 Regression analysis

From the trend observed for UCS and *Mc/Cc* for the laterite-cement mixture in this study a regression analysis was carried out to develop a model that will fit the data obtained. The test data were found to be well represented by a power function as given in equation 1 for the range of moisture content considered. A and B are constants with values shown in Table 2 for all the curing periods and range of water content used.

$$UCS = A\left(\frac{Mc}{Cc}\right)^{-B} \quad \text{......................................} 1$$

Table 2:Values of constants A and B and the R^2 values for each of the regression models

RWC (%)	Curing periods (Days)	A	B	R^2
30	28	3585.2	0.852	0.9905
	14	3066.4	0.878	0.9837
	7	2814.0	0.911	0.9961
45	28	1143.5	0.374	0.9961
	14	1056.5	0.438	0.8720
	7	918.35	0.535	0.9705
60	28	294.39	0.160	0.6424
	14	381.97	0.388	0.9286
	7	265.06	0.305	0.7622

3.5 Comparison of actual laboratory results of UCS and predicted values of UCS

The measured laboratory UCS was compared with the predicted values obtained from the regression models and the results are presented in Tables 3(a-c). It can be observed that the difference between the predicted and the measured values are generally less than 10% on average. This suggest that for cement treated laterite soil at high water content, the ratio of water content and cement content can be used to reasonably predict the strength of the mixture.

Table 3(a): Comparison of actual laboratory results of UCS and predicted values of UCS for 30% Mc

Curing Days	Laboratory Values of UCS (kN/m^2)				Predicted UCS values (kN/m^2)			
	3% Cc	6% Cc	9% Cc	12% Cc	3% Cc	6% Cc	9% Cc	12% Cc
7	343.20	652.80	955.18	1202.20	345.40	647.47	939.68	1221.23
14	389.60	825.22	1022.44	1348.00	406.09	746.33	1065.47	1371.63
28	496.40	963.82	1210.22	1675.50	504.09	909.89	1285.34	1642.36

Table 3(b): Comparison of actual laboratory results of UCS and predicted values of UCS for 45% Mc

Curing Days	Laboratory Values of UCS (kN/m^2)				Predicted UCS values (kN/m^2)			
	3% Cc	6% Cc	9% Cc	12% Cc	3% Cc	6% Cc	9% Cc	12% Cc
7	218.16	296.58	418.14	438.50	215.67	312.50	388.20	452.79
14	341.82	377.85	563.34	600.80	322.65	437.11	522.06	592.16
28	419.22	527.80	625.02	705.25	415.32	538.22	626.35	697.50

Table 3(c): Comparison of actual laboratory results of UCS and predicted values of UCS for 60% Mc

Curing Days	Laboratory Values of UCS (kN/m^2)				Predicted UCS values (kN/m^2)			
	3% Cc	6% Cc	9% Cc	12% Cc	3% Cc	6% Cc	9% Cc	12% Cc
7	112.52	122.21	134.58	182.55	106.29	131.32	148.61	162.24
14	123.21	150.95	170.36	220.30	119.46	156.33	182.96	204.56
28	190.35	191.13	204.84	246.81	182.29	203.67	217.32	227.55

4. CONCLUSION

The following are conclusions that can be drawn from the results of this study:

1. Both water content, cement content and curing period as well as Mc/Cc affects the UCS development of the cement treated laterite soil. UCS was found to decrease with increasing Mc to a value of 235kN/m^2 when Mc was 2.0LL and at 12% cement content and 28 days curing period, a peak UCS value of 1675kN/m^2 was achieved.
2. The data obtained for laterite-cement mixture in this study was found to fit a power function with constants obtained for each curing periods.
3. The regression model developed was found to reasonably predict the UCS of the cement –laterite mixture

4. The observed difference between predicted and measured UCS values was generally less than 10% on average suggesting that the models developed can be used to predict strength of laterite-cement mixture obtained from Zaria in Northern Nigeria.

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