International Journal of Mining and Geo-Engineering

IJMGE

IJMGE 52-1 (2018) 37-42

DOI: 10.22059/ijmge.2017.240176.594690

Predicting the Behaviour of Stabilized Lateritic Soils Treated with Green Crude Oil (GCO) by Analysis of Variance Approaches

Onyelowe Kennedy [a, *], Onwa Kelechi [b], Uwanuakwa Ikenna [c]

[a] Department of Civil Engineering, Michael Okpara University of Agriculture, Umudike, P. M. B. 7267, Umuahia 440109, Abia State, Nigeria

[b] Department of Civil Engineering, Faculty of Engineering, University of Uyo, Nigeria

[c] Department of Civil Engineering, Near East University, Lefkosa, Mersin 10, Turkey

Article History:

Received: 21 August 2017,

Revised: 07 December 2017,

Accepted: 29 December 2017.

ABSTRACT

The behaviour of the stabilized lateritic soil obtained from Amaoba, Nigeria treated with green crude oil was statistically studied using analysis of variance with interaction, Kruskal-Wallis test, and expected mean square methods to validate the effect of the additive on the strength properties of the stabilized soil. First a preliminary test was conducted on the soil to classify the soil as an A-2-6 soil according to the AASHTO classification system. The soil was treated with varying percentages of crude oil; 0, 2, 4, and 6% by weight of the soil. The results obtained showed that the GCO improved the strength properties of the treated soil. Finally the prediction model was used to validate the reaction that brought about strength gain, flocculation, carbonation, cation exchange and densification of the stabilized soil matrix. The three analyses of variance approaches agreed on the hypotheses tests conducted, which rejected the null hypotheses and showed that, to achieve soil stabilization, there must be interaction between the additives and the treated lateritic soil and different percentage by weight of treatment affect the treated soil in different ways.

Keywords : *Analysis of Variance; Expected Mean Square; Geotechnical Engineering; Soil Stabilization; Kruskal-Wallis Test; Soil Strength Behaviour*

1. Introduction

The behaviour of the stabilized lateritic soils has been evaluated by different researchers under different loading conditions in the laboratory through various analytical and numerical methods [1-6]. Right from the rise of soil stabilization and soil strength improvement in the field of Geotechnical engineering, researchers and experts have adopted many methods and approaches in the stabilization operation [1; 7; 8; 9;10]. From the era of purely mechanical stabilization to mechanical plus chemical to mechanical plus chemical plus biodegradable additive or the bye-product of biodegradable additives; ash materials, soil stabilization has improved in various ways [11; 12; 13]. Lateritic soil as a construction material that plays a vital role in the field of Geotechnical engineering, highway engineering and civil engineering as a whole has been faced with diverse techniques and technologies aimed at improving its quality and property for the purpose of efficient engineering service delivery [14; 15; 16]. As a result, many more methods have been adopted to certify the veracity of some of the practical, numerical, analytical, etc. methods [2; 3; 4; 8]. One of those employed in recent times is the analysis of variance [2; 4; 17]. The lateritic soil stabilization adopts the method of treatment of the soil matrix with varying degrees of additive in the laboratory and the behavioural change in the Geotechnical properties of the treated soil observed to determine the best results suitable for the engineering operation of choice [1; 3; 4; 8; 17]. Through the analysis of variance approach, different degrees of treatments carried out on the soil are evaluated for validity and possible interaction between its components to arrive at a certain degree of acceptance [17]. It is through interaction between the components of the treated soil that the chemical reactions that take place like the cation exchange, hydration, flocculation, double diffused layer build up, etc. can possibly take place and leading to densification and hardening or strength gain of the stabilized matrix [5; 17; 18; 19]. So, the test for this interaction proves to be very vital to ascertain the conclusions being made at the end of a stabilization process and validate the decisions we make [17]. The aim of this research work was to predict the behaviour of the stabilized lateritic soil treated with green crude oil (GCO) [9]. By green it means unadulterated crude oil with no other materials or impurities contained in it. The research has the following objectives; (i) to evaluate and confirm the effects of GCO on the Geotechnical properties of lateritic soils, and (ii) to predict through three statistical models the behaviour of the treated lateritic soil with respect to interaction, variation of treatments and the effect of the different treatments on the block of responses or results [18; 19; 20; 21].

2. Technical Approach

The technical approach was taken in three phases; collection and preparation of materials (lateritic soil and Green Crude Oil), preliminary and contamination laboratory exercises and formulation of the parametric equations and models of the laboratory results and through the application of statistical laws of the two-way analysis of variance of interaction.

2.1. Materials

Crude Oil was collected from the Eleme Petrochemical Industry, Portharcourt, Nigeria. This was used in the proportions of 0%, 2%, 4% and 6% by weight to contaminate the lateritic soil. Ordinary Portland cement was used as a binder at a fixed percentage of 5%. Disturbed lateritic soil sample used for this study was collated from a borrow pit

* Corresponding author Tel: +2348039547350. *E-mail address:* konyelowe@mouau.edu.ng (O. Kennedy).

located at Amaba Oboro, Ikwuano Local Government area, on latitude of 05˚28 '36.700" North and longitude 07°32'23.170" East from a depth of 2 meters, a distance of 100m off Umuahia-Ikot Ekpene Road, Umuahia, Nigeria [22] as shown in Fig. 1. The sample collected was in solid state and reddish brown in colour. It was air dried in trays for six days, after which the soil was gently crushed.

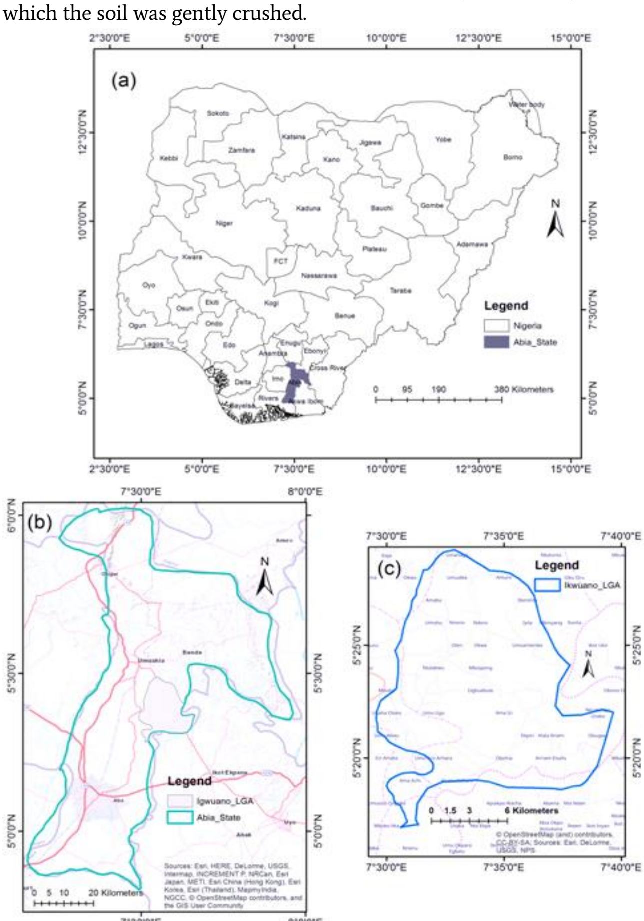

Fig. 1. Test Sample Location Map.

2.2. Laboratory Methods

The following conventional tests were conducted on the natural lateritic soil and the contaminated soil; Sieve Analysis Test: this was conducted with a vertically arranged sieve sizes mounted on an automatic shaker in accordance with BS 1377-2 [24] and NGS [25], Compaction Test (Standard Proctor Test): this was conducted with 2016 ELE Automatic Compactor Machine in accordance with BS 1377-2 [23]; BS 1924 [25] and NGS [24], California Bearing Ratio Test (CBR): conducted with a 2015 S211 KIT CBR penetration machine, motorized 50KN ASTM used to load the penetration piston into the soil sample at a constant rate of 1.27 mm/min (1 mm/min to BS Spec.) and to measure the applied loads and piston's penetrations at determined intervals in accordance with BS 1377-2 [24]; BS 1924 [25] and NGS [24], Atterberg Limit Test: was conducted using a 2013 cassagrande apparatus in accordance with BS 1377-2 [23]; BS 1924 [25] and NGS [24]. Unconfined Compressive Strength (UCS) Test conducted with a 2015 LoadTrac III load frame apparatus in accordance with BS 1377-2 [23]; BS 1924 [25] and NGS [24], Specific Gravity Test was conducted by Pycnometer method in accordance with BS 1377-2 [24] and NGS [25], and Chemical Composition Test on the natural soil sample in accordance with BS 1377-2 [24] and NGS [25] and results were obtained.

2.3. Parametric Formulation of the Null Hypothesis Testing

Test of null hypothesis is a test that leads to a decision to accept or reject the hypothesis under consideration in an engineering design and its allied disciplines. Two hypotheses are involved, (i) H_o, which is the null hypothesis and (ii) H_A, which is the alternative hypothesis. If H_o is false, then H_A is true and vice versa. In carrying out a test, we may erroneously reject a hypothesis we ought to have accepted and vice versa. There are two types of errors that could be committed in this operation; (i) Error Type A: when one rejects H_o when it is true and the probability of committing this error is α and (ii) Error Type B: when one fails to reject H_o when H_A is true and the probability of committing this error is 1-α, where α is the level of significance. The three methods of hypothesis testing in this soil stabilization research operation can be formulated as follows [19-21].

2.3.1. Analysis of Variance with Interaction Method

In the two-way ANOVA with interaction, the linear equation is gen by,

$Y_{ijh} = \mu + \alpha_i + \beta_j + \gamma_{ij} + e_{ijh}$ (1)

For, i= 1, 2...k is the treatment component

j= 1, 2...n is the block component

h= 1, 2...r is the interaction component

μ= the residual component

Where,

$$\sum_{i=1}^{k} \alpha_i = 0 \quad (2)$$

$$\sum_{j=1}^{n} \beta_i = 0 \quad (3)$$

$$\sum_{i=1}^{k} \gamma_{ij} = 0 \text{for each j} \quad (4)$$

$$\sum_{j=1}^{n} \gamma_{ij} = 0 \text{for each I} \quad (5)$$

Also, e_{ijh} is the value of knr independent random variables having normal distributions with zero means and common variance (σ^2). The three null hypotheses to be tested are the treatment effects, block effects and interaction effects. Considering the observations, the sum of squares identity is given by [20],

SST = SSTr + SSB + SSI + SSE (6)

Where,

SST = total sum of squares

SSTr = treatment sum of squares

SSB = block sum of squares

SSI = interaction sum of squares

SSE = error (residual) sum of squares

But [20],

$$SST = \sum_{i=1}^{k} \sum_{j=1}^{n} \sum_{h=1}^{r} Y_{ijh}^2 - \frac{T^2}{knr} \quad (7)$$

$$SSTr = \frac{1}{n} \sum_{i=1}^{k} T_i^2 - \frac{T^2}{kn} \quad (8)$$

$$SSB = \frac{1}{kn} \sum_{i=1}^{n} T_j^2 - \frac{T^2}{knr} \quad (9)$$

$$SSI = \frac{1}{r} \sum_{i=1}^{k} \sum_{j=1}^{n} T_{ij}^2 - \frac{T^2}{knr} - SSTr - SSB \quad (10)$$

$$SSE = SST - SSTr - SSB - SSI \quad (11)$$

Where

T = grand total of all the observations

T_i = total of all the observations for the ith treatment

T_j = total of all the observations for the jth treatment

T_{ij} = total of r observations where the ith treatment is used in combination with j[th] block

2.3.2. ANOVA Nonparametric rank transformation method by Kruskal-Wallis Test

This is the hypothesis testing method developed by Kruskal and Wallis in 1952 where the experimenter may wish to use an alternative procedure to the F test analysis of variance that does not depend on the assumptions of F test. K-W test is used to test the null hypothesis H_o that n treatments on a sample is identical against the alternative hypothesis H_A that some of the treatments generate observations that vary from others. This is a nonparametric alternative to the usual ANOVA. To perform this operation, the observations Y_{ij} are ranked in ascending order and each observation is replaced by its rank, say R_{ij} and let R_i be the sum of ranks in the i[th] treatment. The test statistic is [20; 21] ith treatment. The test statistic is [20; 21].

Table 1. Summary of the two-way ANOVA with interaction [19-21].

Source of Variation	Degree of Freedom (DF)	Sum of Squares (SS)	Mean Sum of Squares (MSS)	$F_{Computed}$
Treatments (k)	k-1	SSTr	$MSSTr = \frac{SSTr}{DF}$	$F_{Tr}=\frac{MSSTr}{MSSE}$
Blocks (n)	n-1	SSB	$MSSB = \frac{SSB}{DF}$	$F_B=\frac{MSSB}{MSSE}$
Interaction (r)	(k-1)(r-1)	SSI	$MSSI = \frac{SSI}{DF}$	$F_I=\frac{MSSI}{MSSE}$
Error(Residuals)	kn(r-1)	SSE	$MSSE = \frac{SSE}{DF}$	
Total	knr	SST		

$$H = \frac{1}{S^2}\left[\sum_{i=1}^{a}\frac{R_i^2}{n_i} - \frac{N(N+1)^2}{4}\right] \quad (12)$$

But,

$$S^2 = \frac{1}{N-1}\left[\sum_{i=1}^{a}\sum_{j=1}^{n_i} R_{ij}^2 - \frac{N(N+1)^2}{4}\right] \quad (13)$$

Where,

S^2 = variance of the ranks
n_i = number of observations in ith treatment
R_i = sum of the ranks in the ith treatment
N = total number of observations
a= number of treatments

H is distributed approximately as X_a^2 under the null hypothesis for n_i < 5, therefore [19],

$$H > X_{(\alpha,a)}^2 \quad (14)$$

If the condition in Eq 14 is met, the null hypothesis is rejected.

Where,

α= the degree of significance

2.3.3. Expected Mean Square Method

A full treatment hypothesis study using the 'Expected Mean Square' (EMS) method is quite technical. This method informs the experimenter what values to achieve in a given mean square (MS) statistic under either the null or an alternative distribution, on average over experimental results [20; 21]. For k population treatment means, we can define [20; 21];

$$\bar{\upsilon} = \frac{\sum_{i=1}^{k}\mu_i}{k} \quad (15)$$

as the of the population of experimental treatment means, and the deviation is [20];

$$\lambda_i = \mu_i - \bar{\upsilon} \quad (16)$$

Hence the variance is calculated as [17; 19; 21]

$$\sigma_i^2 = \frac{\sum_{i=1}^{k}\lambda_i^2}{k-1} \quad (17)$$

From the results of Eq. 17, the null hypothesis is fixed to be, H_o: σ_i^2=0 for EMS.

Where,

μ_i = all the outcomes or observations in the population
$\bar{\upsilon}$ = mean of the ith treatment outcomes
k = number of populations
λ_i = deviation of the ith outcomes from the mean

2.4. Decision Rules

2.4.1. Analysis of Variance with Interaction Method

- If F_{Tr}> F_α[k-1, kn(r-1)], reject H_o: a hypothesis that the treatment of the lateritic soil with GCO in percentages by weight in the stabilization operation has no effect on the strength properties of the treated soil and accept H_A [20; 21].
- If F_B> F_α[n-1, kn(r-1)], reject H_o: a hypothesis that there is no significant difference in the behaviour of the various strength properties of the GCO treated lateritic soil and accept H_A [20; 21].
- If F_I> F_α[(n-1) (k-1), kn(r-1)], reject H_o: a hypothesis that the interaction effect between the soil strength properties and the additive proportion on the behaviour and performance of the stabilized lateritic is zero or insignificant and accept H_A [20; 21].

2.4.2. ANOVA Nonparametric rank transformation method by Kruskal-Wallis Test

- If H >$X_{(0.01,n)}^2$; reject the null hypothesis H_o that the treatments does not differ with the varying percentages by weight of 0%, 2%, 4% and 6% GCO additive [19; 21].

2.4.3. Expected Mean Square Method

- If $\sigma^2 >$ 0; reject the null hypothesis H_o that there was no interaction and no variation on the strength properties of the GCO treated soil [19].

3. Results and Discussions

Table 2 shows the preliminary tests conducted on the lateritic soil and the GCO which classified the soil as an A-2-6 soil, highly plastic and dense.

Table 2. Summary of the lateritic soil preliminary test results.

Property	NMC	PL	LL	PI	C_u	C_c	G_s	$G_{s\ of\ Oil}$
Result	13.49%	18%	40%	22	4.23	4.54	2.6	0.83

NMC = natural moisture content

Table 3 shows the observations from the stabilization operation conducted on the lateritic soil and the sum of i[th] and j[th] observations.

Table 3. Population of Geotech results and observations of the GCO treated lateritic soil.

Test	GCO Treatments % by weight				
	0	2	4	6	T_j
CBR (%)	50	120	270	340	780
MDD (g/cm³)	1.85	1.94	1.91	1.90	7.6
OMC (%)	16.2	12.2	13	13.4	54.8
Void Ratio	0.60	0.59	0.51	0.50	2.2
Coeff of Vol. Change (m²/kN)	0.003	0.0011	0.0018	0.0011	0.007
Compression Index	0.045	0.018	0.022	0.016	0.101
Coeff of Compressibility (m²/kN)	0.0046	0.002	0.0024	0.0019	0.0109
Plasticity Index (%)	22.0	17.4	20.8	18.5	78.7
T_i	90.70	152.15	306.25	374.32	923.42

Where,

T_i = total number of i[th] observations in the block

T_j = total number of jth observations in the block

$\sum_{i=1}^{k}\sum_{j=1}^{n}\sum_{h=1}^{r}Y_{ijh}^2$ = sum of the squares of each of the observations,

= 207737.1555

$\frac{T^2}{knr} = \frac{923.42^2}{8x4x4}$ (k=8; n=4; r=4) = 6661.738

SST = 207737.1555- 6661.738 = 201075.4175

SSTr $= \frac{1}{n}\sum_{i=1}^{k}T_i^2 - \frac{T^2}{kn} = \frac{1}{4}[265278.3677] - 26646.95 = 66319.59 - 26646.95 = 39672.64$

SSB $= \frac{1}{kn}\sum_{i=1}^{n}T_j^2 - \frac{T^2}{knr} = \frac{1}{8x4}[617659.3404] - 6661.738 = 19301.85 - 6661.739 = 12640.116$

SSI $= \frac{1}{r}\sum_{i=1}^{k}\sum_{j=1}^{n}T_{ij}^2 - \frac{T^2}{knr}$ - SSTr – SSB $= \frac{1}{3}[207737.1555] - 6661.738 - 39672.64 - 12640.116 = 10271.22$

SSE = SST – SSTr – SSB – SSI

SSE = 201075.4175 – 39672.64 – 12640.116 – 10271.22 = 138491.44

Table 4 shows the two way analysis of variance results with interaction computed for the hypotheses testing on the effect of the GCO treatment on the strength properties of the lateritic soil with respect to the block of observations and interaction between the additive and the soil over the residuals.

Table 4. The two-way analysis of variance with interaction for the stabilized lateritic soil treated with GCO.

Source of Variation	Degree of Freedom (DF)	Sum of Squares (SS)	Mean Sum of Squares (MSS)	$F_{Computed}$
Treatments (k)	k-1 = 7	SSTr = 39672.64	$MSSTr = \frac{SSTr}{DF}$= 5667.52	$F_{Tr}=\frac{MSSTr}{MSSE}$= 4.44
Blocks (n)	n-1 = 3	SSB =12640. 116	$MSSB = \frac{SSB}{DF}$= 4213.37	$F_B=\frac{MSSB}{MSSE}$= 3.298
Interaction (r)	(k-1)(r-1)= 21	SSI =26119.58	$MSSI = \frac{SSI}{DF}$= 1243.79	$F_I=\frac{MSSI}{MSSE}$= 0.974
Error(Residuals)	kn(r-1)= 96	SSE = 122643.08	$MSSE = \frac{SSE}{DF}$= 1277.53	
Total	knr= 128	SST= 201075.4175		

Application of decision rules which states,

- If $F_{Tr} > F_\alpha$ [k-1, kn(r-1)], Reject H_o : a hypothesis that the treatment of the lateritic soil with admixtures in percentages by weight in the stabilization operation has no effect on the strength properties of the treated soil. However,
- $F_{Tr=}4.44 > F_{\alpha=0.05}$ [7, 96] = 2.12, therefore, accepted the alternative hypothesis which states there are significant effects in the strength properties e.g. CBR and MDD of the GCO treated soil.
- If $F_B > F_\alpha$[n-1, kn(r-1)], reject H_o: a hypothesis that there is no significant difference in the behaviour of the various strength properties of the GCO treated lateritic soil. However,
- $F_{B=}3.298 > F_{\alpha=0.05}$ [3, 96] = 2.71, therefore, accepted the alternative hypothesis which states there are significant differences in the behaviour of the various strength properties e.g. CBR and MDD of the GCO treated lateritic soil.
- If $F_I > F_\alpha$[(n-1) (k-1), kn(r-1)], reject H_o: a hypothesis that the interaction effect between the soil strength properties and the additive proportion on the behaviour and performance of the stabilized lateritic is zero or insignificant. However,
- $F_{I=}0.974 > F_{\alpha=0.05}$ [21, 96] = 0.715, therefore, accept the alternative hypothesis which states there is a significant interaction between the lateritic soil and the additive which brought about carbonation, hydration, cation exchange, double diffused layer formation, densification, flocculation and stabilization.

Table 5 shows the ANOVA nonparametric rank transformation method according to Kruskal-Wallis test conducted on the GCO treated lateritic soil to determine by computing the variance of the ranked observations of the laboratory test results, to establish the hypothesis that the effects of the treatments differ with the varying percentages by weight of 0%, 2%, 4% and 6% GCO.

The test statistics is [17; 19; 21],

$$H = \frac{1}{S^2}\left[\sum_{i=1}^{a}\frac{R_i^2}{n_i} - \frac{N(N+1)^2}{4}\right] \quad (18)$$

But [17; 19; 21],

$$S^2 = \frac{1}{N-1}\left[\sum_{i=1}^{a}\sum_{j=1}^{n_i}R_{ij}^2 - \frac{N(N+1)^2}{4}\right] \quad (19)$$

Where,

S^2 = variance of the ranks

n_i = number of observations in ith treatment = 4

R_i = sum of the ranks in the ith treatment

N = total number of observations = 32

a= number of treatments = 4

$$S^2 = \frac{1}{31}\left[11439.5 - \frac{32(33)^2}{4}\right] = \frac{1}{31}[11439.5 - 8712] = 87.98$$

Therefore,

$$H = \frac{1}{87.98}\left[\frac{45522}{4} - 8712\right] = \frac{1}{87.98}[11380.5 - 8712] = 30.33$$

Table 5. ANOVA Nonparametric rank transformation method by Kruskal-Wallis Test.

GCO Treatment % by weight		0	2	4	6	R_i
`CBR (%)	R	50	120	270	340	
	$Rank_R$	29	30	31	32	122
MDD (g/cm³)	d	1.85	1.94	1.91	1.90	
	$Rank_d$	17	20	19	18	74
OMC (%)	w	16.2	12.2	13	13.4	
	$Rank_w$	24	21	22	23	90
Void Ratio	r	0.60	0.59	0.51	0.50	
	$Rank_r$	16	15	14	13	58
Coeff of Vol.	c	0.003	0.0011	0.0018	0.0011	
Change (m²/kN)	$Rank_c$	7	1.5	3	1.5	13
Compression	In	0.045	0.018	0.022	0.016	
Index	$Rank_{In}$	12	10	11	9	42
Coeff of	Cc	0.0046	0.002	0.0024	0.0019	
Compressibility (m²/kN)	$Rank_{Cc}$	8	5	6	4	23
Plasticity Index	I_p	22.0	17.4	20.8	18.5	
(%)	$Rank_{Ip}$	28	25	27	26	106

Because H > $X_{0.01,4}^2$ = 13.28, the null hypothesis was rejected and it is concluded that the treatments differ which proved that the varying percentages by weight treatments of 0%, 2%, 4% and 6% with GCO reacted in different ways and gave different results from which the satisfactory observation with respect to design standards was chosen. This method is a powerful stochastic tool called rank transformation.

Table 6 shows the hypothesis testing of the results of the GCO treated lateritic soil with the Expected Mean Square (EMS) method. The hypothesis testing was carried out on all the observations of the different geotechnical test conducted on the treated soil to determine the effect of the GCO treatment on the soil properties.

Table 6. Expected Mean Square method results of GCO treated lateritic soil.

GCO Treatment % by weight		0	2	4	6		Hypothesis testing.
CBR (%)	R	50	120	270	340	$\bar{\upsilon}_R$=195	$H_o: \sigma_R^2$=0
	$\lambda_{i(R)}$	-145	-75	75	145		But σ_R^2>0, Reject H_o
	$\lambda_{i(R)}^2$	21025	5625	5625	21025	σ_R^2=17766.7	
MDD (g/cm^3)	d	1.85	1.94	1.91	1.90	$\bar{\upsilon}_d$=1.9	$H_o: \sigma_d^2$=0
	$\lambda_{i(d)}$	-0.05	0.04	0.01	0		But σ_d^2>0, Reject H_o
	$\lambda_{i(d)}^2$	.0025	.0016	.0001	0	σ_d^2=0.0014	
OMC (%)	w	16.2	12.2	13	13.4	$\bar{\upsilon}_w$=13.7	$H_o: \sigma_w^2$=0
	$\lambda_{i(w)}$	2.5	-1.5	-0.7	-0.3		But σ_w^2>0, Reject H_o
	$\lambda_{i(w)}^2$	6.25	2.25	0.49	0.09	σ_w^2=3.027	
Void Ratio	r	0.60	0.59	0.51	0.50	$\bar{\upsilon}_r$=0.55	$H_o: \sigma_r^2$=0
	$\lambda_{i(r)}$	0.05	0.04	-0.04	-0.05		But σ_r^2>0, Reject H_o
	$\lambda_{i(r)}^2$	.0025	.0016	.0016	.0025	σ_r^2=0.0027	
Coeff of Vol. Change (m^2/kN)	c	0.003	0.0011	0.0018	0.0011	$\bar{\upsilon}_c$=0.00175	$H_o: \sigma_c^2$=0
	$\lambda_{i(c)}$	0.00125	-0.00065	.00005	-.00065		But σ_c^2>0, Reject H_o
	$\lambda_{i(c)}^2$	.0000016	.00000042	.000000002	.000042	σ_c^2=0.000015	
Compression Index	In	0.045	0.018	0.022	0.016	$\bar{\upsilon}_{In}$=0.02525	$H_o: \sigma_{In}^2$=0
	$\lambda_{i(In)}$	.01975	-.00725	-.00325	-.00925		But σ_{In}^2>0, Reject H_o
	$\lambda_{i(In)}^2$	.00039	.000053	.000011	.000086	σ_{In}^2=0.00018	
Coeff of Compressibility (m^2/kN)	Cc	0.0046	0.002	0.0024	0.0019	$\bar{\upsilon}_{Cc}$=0.002725	$H_o: \sigma_{Cc}^2$=0
	$\lambda_{i(Cc)}$	.001875	-.000725	-.000325	-.00083		But σ_{Cc}^2>0, Reject H_o
	$\lambda_{i(Cc)}^2$	.0000035	.00000053	.00000011	.000069	σ_{Cc}^2=0.000024	
Plasticity Index (%)	I_p	22.0	17.4	20.8	18.5	$\bar{\upsilon}_{Ip}$=19.675	$H_o: \sigma_{Ip}^2$=0
	$\lambda_{i(Ip)}$	2.33	-2.28	1.13	-1.18		But, σ_{Ip}^2>0, Reject H_o
	$\lambda_{i(Ip)}^2$	5.429	5.198	1.28	1.39	σ_{Ip}^2=4.43	

The null hypothesis (H_o) that there are no variations ($\sigma^2 \leq 0$) in the effect of the GCO treatment on the strength properties of the lateritic soil was rejected for all the laboratory investigation because $\sigma^2 > 0$ satisfied the laboratory results of the lateritic soil stabilization. This proved that the varying degrees of treatment on the engineering soil with GCO improved the properties of the soil by interaction hence its use as an engineering material for sub-grade and sub-base construction [26].

4. Conclusion

From the foregoing, it can be concluded that; (i) the effect of the GCO on the strength properties of the stabilized lateritic soil has been established by the statistical prediction according to ANOVA with interaction, Kruskal-Wallis test method and EMS method, (ii) the interaction that characterized the chemical reactions that take place in an additive (GCO) treated soil, which gives rise to the carbonation, hydration, cation exchange, flocculation, densification, diffused double layer formation and strength gain in soil stabilization operation is valid, (iii) the varying proportions by weight of treatment with additives have different effects on the strength properties of the treated lateritic soil, and (iv) the three hypothesis tests agreed on the results of the statistical prediction operation.

Acknowledgments

Mohammed Edris was of great help towards the success of this work.

REFRENCES

[1] Bolarinwa A, Adeyeri JB and Okeke TC (2017) Compaction and Consolidation Characteristics of Lateritic Soil of a Selected Site in Ikole Ekiti, Southwest Nigeria. Nigerian Journal of Technology (NIJOTECH) Vol. 36, No. 2, pp. 339 – 345. http://dx.doi.org/10.4314/njt.v36i2.3

[2] Bartlett SF (2012) Numerical Methods in Geotechnical Engineering. Course notes, Department of Civil and Environmental Engineering, The University of Utah.

[3] Okafor FO and Egbe EA (2017) Models for Predicting Compressive Strength and Water Absorption of Laterite-Quarry Dust Cement Block Using Mixture Experiment. Nigerian Journal of Technology (NIJOTECH) Vol. 36, No. 2, pp. 366 – 372. http://dx.doi.org/10.4314/njt.v36i2.7

[4] Okonkwo UN, Agunwamba JC and Iro UI (2016) Geometric Models For Lateritic Soil Stabilized With Cement And Bagasse Ash. Nigerian Journal of Technology (NIJOTECH) Vol. 35, No. 4, pp. 769 – 777. http://dx.doi.org/10.4314/njt.v35i4.11

[5] Anyaogu L and Ezeh JC (2013) Optimization of Compressive Strength of Fly Ash Blended Cement Concrete Using Scheffe's Simplex Theory. Natural and Applied Sciences, vol. 4, no. 2, pp. 177-186.

[6] Anand JP (2016) Advances in ground modification with chemical additives: From theory to practice. Elsevier Transportation Geotechnics 9, 123–138. http://dx.doi.org/10.1016/j.trgeo.2016.08.004

[7] Etim RK, AO Eberemu and KJ Osinubi (2017) Stabilization of black cotton soil with lime and iron ore tailings admixture. Elsevier Transportation Geotechnics 10 (2017) 85–95. http://dx.doi.org/10.1016/j.trgeo.2017.01.002

[8] Okafor FO and Ewa DE (2012) Predicting The Compressive Strength Of Obudu Earth Blocks Stabilized With Cement Kiln Dust. Nigerian Journal of Technology (NIJOTECH), Vol. 31, No. 2, pp. 149-155.

[9] Onyelowe KC (2017) Nanosized palm bunch ash stabilization of lateritic soil for construction purposes. International Journal of Geotechnical Engineering, http://dx.doi.org/10.1080/19386362.2017.1322797

[10] Onyelowe KC (2017) Nanostructured Waste Paper Ash Stabilization of Lateritic Soils for Pavement Base Construction Purposes" Electronic Journal of Geotechnical Engineering (22.09), pp 3633-3647.

[11] Cheng C, McDowell GR and Thom NH (2013) A study of geogrid reinforced ballast using laboratory pull-out tests and discrete element modelling, Geomechanics and

Geoengineering, 8:4, 244-253. http://dx.doi.org/10.1080/17486025.2013.805253

[12] Cuelho EV and SW Perkins (2017) Geosynthetic subgrade stabilization – Field testing and design method calibration. Elsevier Transportation Geotechnics 10 (2017) 22–34. http://dx.doi.org/10.1016/j.trgeo.2016.10.002

[13] Ojuri OO, AA Adavi, OE Oluwatuyi (2017) Geotechnical and environmental evaluation of lime–cement stabilized soil–mine tailing mixtures for highway construction. Elsevier Transportation Geotechnics 10 (2017) 1–12. http://dx.doi.org/10.1016/j.trgeo.2016.10.001

[14] Gidigasu MD and Dogbey JLK (1980) Geotechnical Characterization of Laterized Decomposed Rocks for Pavement Construction in Dry Sub-humid Environment". 6th South East Asian Conference on Soil Engineering, Taipei, 1, 493-506

[15] Abdullahi M, Ojelade GO and Auta SM (2017) Modified Water-Cement Ratio Law for Compressive Strength of Rice Husk Ash Concrete. Nigerian Journal of Technology (NIJOTECH) Vol. 36, No. 2, April 2017, pp. 373 – 379. http://dx.doi.org/10.4314/njt.v36i2.8

[16] Mousavi SE (2017) Shear strength behavior in the interface of contaminated soil with bio-diesel oil and geosynthetics. Elsevier Transportation Geotechnics 10 (2017) 62–72. http://dx.doi.org/10.1016/j.trgeo.2016.12.003

[17] Montgomery DC (2001) Design and Analysis of Experiments. 5th Edition, John Wiley and Sons, NY

[18] Seltman HJ (2015) Experimental Design and Analysis. Ebook. Setlman. UK

[19] Dean A and Voss D (1999) Design and Analysis of Experiments. Springer, NY

[20] Montgomery DC (2001) Design and Analysis of Experiments, 5th Edition. John Wiley and Son Inc. NY.

[21] Agunwamba JC (2007) Engineering Mathematical Analysis. De-Adroit Innovation, Enugu, Nigeria. Chap 16 and 17. ISBN 978-8137-08-3.

[22] www.google.com (2017) Location of Umuahia. Accessed on January 12, 2017

[23] BS 1377-2 (1990) Methods of Testing Soils for Civil Engineering Purposes, British Standard Institute, London.

[24] Nigerian General Specification (1997) Testing for the selection of soil for roads and bridges, Vol. II.

[25] BS 1924 (1990) Methods of Tests for Stabilized Soil, British Standard Institute, London.

[26] Egamana S and Sule S (2017) Optimisation of Compressive Strength of Periwinkle Shell Aggregate Concrete. Nigerian Journal of Technology (NIJOTECH) Vol. 36, No. 1, pp. 32 – 38. http://dx.doi.org/10.4314/njt.v36i1.5