**Original Research Article**

**EVALUATING THE UNCONFINED COMPRESSIVE STRENGTH RETENTION OF CORN STARCH STABILIZED LATERITIC SOILS**

**ABSTRACT**

This study evaluates the effectiveness of corn starch as a sustainable stabilizer for lateritic soils, focusing on unconfined compressive strength (UCS) retention under wet–dry cycles. A (3,2) Scheffé simplex lattice design was employed to vary lateritic soil, corn starch, and water-to-solids (w/s) ratio across 12 mixes (6 trial, 6 control). Samples were cured for 28 days, then subjected to 12 wet–dry cycles to assess UCS retention. UCS retention ranged from 69.68% to 90.12% for trial mixes and 69.68% to 91.24% for control mixes, indicating strong durability. The best-performing mixes exceeded 90%, confirming corn starch’s potential for long-term stabilization. The Scheffé regression model developed had an R² of 0.998 and an F-value of 1.056 (< F-critical of 5.05), confirming predictive reliability and statistical adequacy. Model coefficients showed corn starch had the greatest influence (β₂ = 87.50), followed by lateritic soil (β₁ = 83.33) and water-to-solids ratio (β₃ = 69.68). Positive interactions between lateritic soil and corn starch (18.82) and between lateritic soil and water-to-solids ratio (43.98) improved retention, while a slight negative effect between corn starch and water-to-solids ratio (−0.72) indicated that excess water could reduce binding. Overall, corn starch significantly improves UCS retention, offering a durable, eco-friendly solution for lateritic soil stabilization.

***Keywords; Unconfined compressive strength retention, Durability, Lateritic soil, corn starch, Scheffe’s regression, simplex lattic design***

1. **Introduction**

Lateritic soils are extensively utilized in subgrade and subbase construction across tropical regions, including West Africa, due to their widespread availability, ease of excavation, and acceptable engineering properties when properly stabilized. These soils, typically residual in origin and rich in iron and aluminum oxides, serve as a critical material in road construction and other geotechnical applications (Adeyemi, 2020). However, the performance of lateritic soils under wet or saturated conditions remains a significant limitation. This challenge stems from their high fines content, variable mineralogy, and high susceptibility to moisture-induced strength loss, factors that contribute to deformation, erosion, and a substantial reduction in load-bearing capacity (Osinubi et al., 2019; Moses & Okogbue, 2021).

To address these limitations, stabilization techniques involving cement, lime, and industrial by-products such as fly ash, ground granulated blast furnace slag (GGBFS), and rice husk ash have been extensively applied. These stabilizers promote pozzolanic reactions, resulting in the formation of calcium silicate hydrate (C-S-H) and other cementitious compounds that improve the unconfined compressive strength (UCS), California Bearing Ratio (CBR), stiffness, and long-term durability of treated soils (Amu et al., 2022; Jinadu et al., 2021). Bello et al. (2020) confirmed that cement and lime-treated soils can achieve UCS values exceeding 1200 kPa, making them suitable for high-load pavement systems. However, the environmental implications, especially the high carbon emissions associated with cement production, and the rising costs of these additives have prompted growing interest in more sustainable, low-impact alternatives.

Among the emerging alternatives, biopolymers such as corn starch, xanthan gum, and guar gum have shown promise as eco-friendly soil stabilizers. These materials are renewable, biodegradable, and non-toxic, aligning with sustainable development goals in geotechnical engineering (Makusa, 2012; Khan et al., 2023). Corn starch, in particular, is a polysaccharide derived from maize with gelling, adhesive, and film-forming properties that facilitate particle bonding and surface sealing in soil matrices (Zhang et al., 2021). As a low-cost and biodegradable additive, corn starch offers dual benefits: enhancing soil engineering properties while reducing reliance on energy-intensive and environmentally harmful stabilizers such as cement and lime (Khan et al., 2023).

Mechanistically, starch molecules form hydrogen bonds with clay particles, creating a semi-rigid matrix that improves soil cohesion, reduces permeability, and resists particle detachment under hydraulic or mechanical loading (Akinwumi et al., 2020; Ng & Woon, 2020). Ng and Woon (2020) demonstrated that starch and similar biopolymers can reduce the permeability of treated soils by over 70%, thereby improving erosion resistance and water stability. Akinwumi et al. (2020) also reported increases in cohesion and internal friction angle, indicating improved shear strength and stability under loading conditions.

Empirical studies provide further support for the mechanical benefits of starch-treated soils. Ayeni et al. (2023) observed UCS improvements of up to 92% in lateritic soils treated with 4–6% corn starch after 7 days of curing, while Akinwumi et al. (2020) reported strength increases of 60–85% in silty clays stabilized with similar dosages over a 14-day period. Jang et al. (2022) found that corn starch not only improved strength but also enhanced workability and compaction behavior, reducing the optimum moisture content and increasing maximum dry density, key properties for field application.

However, the long-term performance of starch-stabilized soils remains a subject of ongoing investigation. Although initial UCS gains are well-documented, the durability of these gains under environmental stressors, particularly wetting-drying and freeze-thaw cycles, is not fully understood. These cyclic conditions, common in tropical climates, can cause the degradation of the bio-bonding matrix due to water solubility and biodegradation, leading to loss of cohesion and increased deformability (Makusa, 2012; Moses & Okogbue, 2021). Zhang et al. (2021) observed strength reductions of up to 40% in starch-treated clays subjected to prolonged moisture exposure, highlighting the need for moisture protection or chemical modification to enhance durability.

In comparative stabilization studies, Bello et al. (2020) found that while starch-stabilized soils did not attain the high UCS levels of cement or lime-treated counterparts, they achieved UCS values in the range of 500–700 kPa at 28 days, sufficient for low-volume roads and lightly loaded infrastructure. Nevertheless, the study emphasized the importance of moisture shielding for maintaining long-term performance. Similarly, Khan et al. (2023) noted that although starch-treated soils are environmentally compatible and leachate-free, their strength gradually diminishes unless chemically modified or blended with more durable agents.

In the context of sustainable infrastructure development, these findings underscore the need to evaluate not only the initial strength improvement but also the residual strength and durability of starch-stabilized soils under conditions that simulate real-world environmental stressors. Unconfined Compressive Strength (UCS), a key index parameter in geotechnical engineering, is particularly valuable for assessing both the immediate and retained mechanical behavior of stabilized soils (Amu & Ogunniyi, 2019). UCS testing allows for a rapid and reliable assessment of soil integrity, making it a preferred tool for evaluating the efficacy of natural stabilizers.

Therefore, this study focuses on assessing the UCS retention of corn starch-stabilized lateritic soils subjected to controlled wetting-drying cycles. By simulating tropical moisture fluctuations, the research aims to establish the long-term performance reliability of starch-treated soils. Ultimately, the goal is to contribute to the growing body of knowledge on biopolymer-based soil stabilization and support the development of eco-friendly, cost-effective strategies for sustainable geotechnical engineering in tropical climates.

1. **Materials and Methods**

**2.1 Materials**

**1. Lateritic Soil**; The lateritic soil sample used in this study was sourced from a borrow pit situated in Choba, Port Harcourt, Nigeria, with geographic coordinates 4.893510°N and 6.910277°E. To ensure its suitability for laboratory analysis, the soil underwent a series of preparatory steps. Only the portion passing through a 4.5 mm sieve was retained for testing, thereby maintaining uniformity and relevance to engineering applications.

Chemical analysis of the soil revealed a silica (SiO₂) to sesquioxide (Al₂O₃ + Fe₂O₃) ratio of 1.78. This value falls within the range of 1.33 to 2.00, confirming the soil’s classification as lateritic according to the criteria outlined by Akije (2015). Moreover, the soil exhibited a low calcium oxide (CaO) content of 0.408%, suggesting a negligible natural cementing potential.

In terms of Atterberg limits, the untreated lateritic soil displayed a liquid limit of 29% and a plastic limit of 13.04%, resulting in a plasticity index of 15.96%. These values indicate moderate plasticity, which is characteristic of lateritic soils commonly found in tropical regions.

The particle size distribution analysis further showed that the soil is predominantly composed of fine-grained materials, consisting of 5% gravel, 55% medium to coarse sand, 35% fine sand, and 15% silt. Within the sand fraction, medium and coarse sand accounted for 30% and 25% of the total soil mass, respectively. This gradation indicates a well-distributed soil texture with a dominance of sandy particles, contributing to its workable and moderately permeable nature.

The natural lateritic soil exhibited a specific gravity of 2.58, which is slightly below but still closely aligned with the typical range of 2.60 to 2.90 for fine-grained soils. This result indicates that the soil is indeed fine-grained and that the specific gravity test was reliably conducted, reflecting the soil’s mineral composition and confirming its classification within the expected range for lateritic materials (Murthy, 2012).

Furthermore, results from the standard Proctor compaction test showed an optimum moisture content (OMC) of 14.5% and a maximum dry density (MDD) of 1.84 g/cm³. These values suggest that the soil has moderate compaction characteristics, which are suitable for engineering applications such as subgrade and subbase construction, particularly after stabilization.

In conclusion, the soil exhibits characteristics consistent with lateritic soils in tropical regions, as defined by established classification systems. Its mineralogical composition, moderate plasticity, and dominant sand fraction make it a suitable candidate for further stabilization and geotechnical improvement studies.

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**2. Corn Starch**; Corn starch is a type of polysaccharide, meaning it is a complex carbohydrate composed of multiple sugar units. It appears as a fine, white powder and is extracted from the endosperm of corn kernels. Commonly utilized as a thickening agent in culinary applications such as cooking and baking, corn starch is also employed as a coating in frying processes to create a crispy outer layer. For this study, corn starch was obtained in a 25 kg bag from Barivan Chemicals, located in Port Harcourt, Rivers State.

3. **Water**; Water of pH of about 6.9 free from deleterious materials sourced from the geotechnical laboratory of the Department of Civil and Environmental Engineering, University of Port Harcourt, was used for experimental investigations.

**2.2 Methods**

The methodology involved developing a simplex lattice design tailored for corn starch-stabilized lateritic soil, followed by the preparation of the stabilized soil using varying proportions of corn starch. The unconfined compressive strength (UCS) was evaluated after 28 days of curing, and durability was assessed through the UCS retention approach. Additionally, the effects of individual mixture components and their interactions were analyzed using the coefficients from the developed Scheffe’s regression model, supported by ANOVA statistics and the visualization of ternary and response surface plots.

**2.2.1 Formulation of Simplex Lattice Design**

The simplex lattice mix design method was adopted to formulate mix proportions for the corn starch-stabilized lateritic soil. As outlined by Oguaghamba and Mama (2018), a (q, m) mixture design, where q denotes the number of mixture components and m represents the polynomial degree or maximum level of component interaction, establishes the simplex coordinate system Xi and determines the total number of design points, N within the simplex lattice, as defined by Equation (1) and Equation (2), respectively.

$X\_{i}=0, \frac{1}{m}, \frac{2}{m},……..1$ (1)

$N= \frac{(q+m-1)!}{m!(q-1)!}$ (2)

In this study, a (3,2) simplex lattice mixture design was employed, where the number 3 represents the three components in the stabilized lateritic soil mixture, and 2 denotes the maximum degree of component interaction assumed. Based on Equations (1) and (2), the corresponding simplex coordinate values (Xi) are 0, ½, and 1, while the number of required design points (N) is 6. This value of N represents the minimum number of experimental runs necessary to develop a valid regression model. According to Scheffé’s mixture theory, the mixture proportions are represented in pseudo (theoretical) mix ratios. Pure components occupy the vertices of the simplex, as illustrated in Figure 1, and a fundamental condition of the model is that the sum of the pseudo mix ratios at any point within the simplex must equal 1. Mathematically, this is expressed as;

$\sum\_{i=1}^{q}X\_{i}=1 $ (3)

In order to satisfy Equation (3), it is necessary to convert actual mix ratios into pseudo mix ratios. The correlation between pseudo and actual mix ratios is expressed as follows:

Z = [A]X (4)

Where: Z = column matrix of real component ratio.

X = column matrix of pseudo component ratio.

[A]= coefficient matrix which is the transpose of the permutation matrix.

In developing the mix design table for lateritic soil stabilization, the permutation matrix [P] in Equation (5) was established based on a review of existing literature on corn starch stabilization and preliminary test data. Corn starch (CS) was incorporated at proportions ranging from 0% to 10% by mass of the lateritic soil, which consequently adjusted the lateritic soil content to range between 90% and 100%. Preliminary tests also informed the selection of the water-to-solid (W/S) ratio, which was constrained between 12% and 16%. This range was chosen to reflect the influence of corn starch on the soil’s moisture requirements, considering that the optimum moisture content for untreated lateritic soil was determined to be 14.5%. These parameter ranges were used to construct the permutation matrix shown in Equation (5). At the vertices of the simplex, the actual mixture component proportions were identified as (0.90; 0.10; 0.12), (0.95; 0.05; 0.14), and (1.00; 0.00; 0.16), representing the soil proportion, corn starch proportion, and water-to-solid ratio, respectively. Arranged in matrix form, these values constitute the permutation matrix [P].

$\left[P\right]= \left[\begin{array}{c}0.900 0.100 0.120 \\0.950 0.050 0.140 \\1.000 0.000 0.160 \end{array}\right]$ (5)

With the corresponding pseudo mix components being;

$\left[X\right]= \left[\begin{array}{c}1.000 0.000 0.000 \\0.000 1.000 0.000 \\0.000 0.000 1.000 \end{array}\right]$ (6)

The transpose of [P] becomes the coefficient matrix [A] as shown in Equation (7)

$\left[A\right]= \left[\begin{array}{c}0.900 0.950 1.000\\ 0.100 0.050 0.000 \\0.120 0.140 0.160 \end{array}\right]$ (7)

Using Equation (4), the pseudo components were converted into actual, or real, mixture components as presented in Table 1. This resulted in six (6) experimental runs for the trial mix investigations. To generate control mix designs for model validation, an additional six (6) design points were created, all satisfying the condition ∑Xi =1. Consequently, the total number of experimental runs amounted to twelve (12) mixes, six for the trial mixes and six for the control mixes. The initial six experimental points were utilized to develop Scheffé’s regression model, while the remaining six were reserved for model validation.

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**Figure 1. (3, 2) Simplex Lattice Structure**

**Table 1: Design Matrix for Trial Mixes of Stabilized soil components**

|  |  |
| --- | --- |
| **N** | **Mix Proportions** |
| **Pseudo Proportions** | **Actual proportions** |
|  | X1 | X2 | X3 | Z1 | Z2 | Z3 |
| 1 | 1 | 0 | 0 | 0.90 | 0.10 | 0.12 |
| 2 | 0 | 1 | 0 | 0.95 | 0.05 | 0.14 |
| 3 | 0 | 0 | 1 | 1.00 | 0.00 | 0.16 |
| 4 | 0.5 | 0.5 | 0 | 0. 925 | 0.075 | 0.13 |
| 5 | 0.5 | 0 | 0.5 | 0.950 | 0.050 | 0.140 |
| 6 | 0 | 0.5 | 0.5 | 0.975 | 0.025 | 0.150 |

***Where; Z1= lateritic soil; Z2 = Corn starch; Z3= w/s***

**Table 2: Design Matrix for Control Mixes of Stabilized soil components**

|  |  |
| --- | --- |
| **N** | **Mix Proportions** |
| **Pseudo Proportions** | **Actual proportions** |
|  | X1 | X2 | X3 | Z1 | Z2 | Z3 |
| 1 | 0.4 | 0.4 | 0.2 | 0.940 | 0.060 | 0.136 |
| 2 | 0.3 | 0.3 | 0.4 | 0.955 | 0.045 | 0.142 |
| 3 | 0.2 | 0.2 | 0.6 | 0.970 | 0.030 | 0.148 |
| 4 | 0.1 | 0.6 | 0.3 | 0. 960 | 0.040 | 0.144 |
| 5 | 0.4 | 0.3 | 0.3 | 0.945 | 0.055 | 0.138 |
| 6 | 0.5 | 0.3 | 0.2 | 0.935 | 0.065 | 0.134 |

***Where; Z1= lateritic soil; Z2 = Corn starch; Z3= w/s***

**2.2.2 Preparation of the Stabilized Soil**

Corn starch stabilized lateritic soil samples were batched by weight using the manual mixing procedure and compacted according to ASTM D698 (2015). Membrane curing was used as the curing method for all produced corn starch stabilized lateritic soil samples for 28 days before testing and durability assessment. Two (2) samples per experimental run were produced as per the developed design of experiment. Figure 2 presents the collection of pictures during preparation of corn starch based stabilized soil samples.



 Weighed corn starch weighed soil sample



 Mixing of soil samples Curing of Stabilized soil samples

**Figure 2. Stabilized Soil Sample Preparation**

**2.2.3 Unconfined Compressive Strength (UCS) Determination**

The UCS of stabilized lateritic soils was determined in accordance to ASTM D2166 (2016) in order to obtain the compressive stress of corn starch stabilized soil samples. During this analysis, 100mm × 200mm cylindrical molds were used. Corn starch based treated soil samples were loaded and the failure load recorded. The UCS was then evaluated using Equation (8).

 $σ\_{u}= \frac{P (in N)}{A (in mm²)}$ (8)

Where, P is the failure load and A is the cross-sectional area of the tested corn starch based stabilized lateritic soil. Figure 3 presents the UCS testing of the corn starch stabilized lateritic soil.



**Figure 3. UCS Testing of the Stabilized Lateritic Soil**

**2.2.4 Durability Assessment in terms of UCS of Stabilized Lateritic Soil**

Durability testing was conducted in accordance with ASTM D2166 (2016). Stabilized specimens underwent 12 wet-dry cycles, each consisting of immersion in water for 5 hours followed by drying in an oven at 60°C for 16 hours. Upon completion of the 12 cycles, the unconfined compressive strength (UCS) was measured, and the UCS retention, used as a measure of material durability, was calculated using Equation (9).

$UCS\_{retention}= \frac{UCS\_{final}}{UCS\_{initial}} X 100$ (9)

Where; UCSfinal is the UCS after the 12th cycle, and UCSinitial is the UCS before the start of the wet-dry cycles.

**2.2.5 Scheffe’s Regression Model Development**

The standard form of the quadratic mixture model according to Scheffe (1958), is given as;

(10)

$$Y = \sum\_{1\leq i\leq q}^{}β\_{i}X\_{i} + \sum\_{i\leq j\leq q}^{}β\_{ij}X\_{i}X\_{j}$$

Where; Y = Expected response; $β\_{i}$, $β\_{ij}$ = Coefficients of the quadratic polynomial;

Xi, Xj = Pseudo proportion of mixture components

For a (3, 2) polynomial model, Equation (10) becomes;

$Y= β\_{1}X\_{1}+ β\_{2}X\_{2}+ β\_{3}X\_{3}+ β\_{12}X\_{1}X\_{2}+ β\_{13} X\_{1}X\_{3}+ β\_{23}X\_{2}X\_{3}$ (11)

Where,

Y = response, which in this study represent the UCS retention of corn starch stabilized lateritic soil

X1 = lateritic soil proportion

X2 = Corn starch proportion

X3 = water/solids ratio

The coefficients of the model according to Scheffe (1958) is expressed as;

 βi= Yi

βij= 4Yij – 2Yi – 2Yj (12)

Where; Yi, Yij correspond to the corn starch stabilized lateritic soil response which is the UCS retention at space points, i and ij respectively.

**2.2.6 Scheffe’s Regression Model Validation**

The developed UCS retention model was validated using the Fisher test (F-test) to assess its adequacy. The F-statistic is the ratio of variance between predicted model responses and experimental values.

The hypotheses for validation were:

Null Hypothesis (H₀): No significant difference exists between experimental and predicted responses.

Alternate Hypothesis (H₁): A significant difference exists between experimental and predicted responses.

The F-test was conducted using the formula:

$F=\frac{S\_{1}^{2}}{S\_{2}^{ 2}}$ (13)

Where; $S\_{1}^{2}$ = Larger of both variances, $S\_{2}^{2}$ = Smaller of both variances**,** calculated as:

$S^{2}=\frac{1}{n-1}\left[\sum\_{}^{}\left(Y- \overbar{Y}\right)^{2}\right]$ (14)

The model is considered adequate if the calculated F-value is lower than the critical value from the F-distribution table. At a 5% significance level, with 5 degrees of freedom, the critical F-value is 5.05. If the calculated F-value is below 5.05, the null hypothesis is accepted, confirming model adequacy. Otherwise, the alternate hypothesis is accepted, indicating model inadequacy.

In another vane, developed models were also subjected to R2 statistics for verification testing. The R2 values were calculated in accordance to Equation (15).

$R^{2}=\frac{Σ(yest-ȳ)^{2} }{Σ(y-ȳ)^{2}}$ (15)

Where; yest = model or estimated value,

 y = experimental value and

 ȳ = mean experimental value

**2.2.7 Effect of Mixture Components on UCS Retention of Corn Starch Stabilized Lateritic Soil**

The influence of individual mixture components and their interactions on the UCS retention of corn starch-stabilized lateritic soil was thoroughly examined using Scheffé’s regression model. The model’s coefficients quantified the effects of each component as well as their combined interactions on UCS retention.

1. **Results and Discussion**

**3.1 UCS Retention of the Stabilized Lateritic Soil**

Figure 4 presents the unconfined compressive strength (UCS) and UCS retention values for both the trial and control mixes of corn starch-stabilized lateritic soil. The UCS retention values for the trial mixes ranged from 69.68% in Trial Mix 3 to 90.12% in Trial Mix 4, while the control mixes recorded a similar range of 69.68% (Control Mix 3) to 91.24% (Control Mix 4). These findings provide a crucial indication of the durability performance of the stabilized soils under simulated environmental stress conditions, specifically wet-dry cycling.

The high UCS retention values observed, particularly those exceeding 85% in both trial and control mixes, demonstrate the ability of corn starch as a biopolymer additive to significantly improve the long-term structural integrity of lateritic soils. According to ASTM D2166 (2011), the UCS test is a reliable measure for evaluating the mechanical performance of stabilized soils, and when coupled with durability testing (e.g., wet-dry cycling), it gives insight into the potential for long-term field performance.

Comparison with existing benchmarks provides further validation. The Nigerian General Specifications for Roads and Bridges (Federal Ministry of Works & Housing [FMW&H], 1997) recommends a minimum UCS of 1.5 MPa for stabilized subbase materials. While the focus here is on UCS retention, the consistently high retention percentages, particularly values above 80%, are indicative of the soil’s resilience and ability to maintain structural integrity after environmental cycling, aligning with values considered acceptable in the literature for durable stabilization (Amu et al., 2011; Ola, 1983; Osinubi et al., 2021).

Notably, the retention values observed in this study surpass those from earlier research on chemical stabilizers. For example, Amu and Ogunniyi (2019) recorded UCS retention ranging from 60% to 80% for cassava peel ash and cement-stabilized soils. The superior performance of corn starch may be attributed to its hydrophilic gel-forming capabilities, which not only improve particle binding but also inhibit moisture ingress, leading to enhanced strength retention (Latifi et al., 2016; Ayeldeen et al., 2017).

Trial Mix 4 and Control Mix 4, which exhibited the highest UCS retention values (90.12% and 91.24%, respectively), were formulated based on optimized mix proportions derived using the Scheffé Simplex Lattice Design. This statistical design approach effectively identified the optimal interactions between lateritic soil, corn starch, and water-to-solid ratio, underscoring its utility in developing high-performance soil mixtures (Montgomery, 2017; Edeh et al., 2022).

In summary, the UCS retention results underscore the potential of corn starch as an environmentally friendly and sustainable stabilizer for lateritic soils. The high retention values meet and in some cases exceed durability thresholds recommended in national standards and found in existing literature, positioning corn starch as a viable alternative to conventional chemical stabilizers for road construction and other geotechnical applications.

**Figure 4. UCS Retention Results of Stabilized Lateritic Soil for Trial and Control Mixes**

**3.2 Scheffe’s Regression Model for UCS Retention of Stabilized Lateritic Soil**

Figure 4 presents the UCS retention of corn starch stabilized lateritic soil for trial and control mix proportions. Response from trial mix proportions were used in the Scheffe’s regression model development while response values from control mixes were used for validation of the developed model. With the aid of Figure 4 in conjunction with Equation (12), the model coefficients of the Scheffe’s (3, 2) regression model for predicting the UCS retention of corn starch stabilized lateritic soil is thus obtained;

β1 = Y1 = 83.33

β2 = Y2 = 87.50

β3 = Y3 = 69.68

$$β\_{12} = 4Y\_{12}- 2Y\_{1}-2Y\_{2}= 4\left(90.12\right)-2\left(83.33\right)-2\left(87.50\right)=18.82 $$

$$β\_{13} = 4Y\_{13}- 2Y\_{1}-2Y\_{3}= 4\left(87.50\right)-2\left(83.33\right)-2\left(69.68\right)=43.98$$

$$β\_{23} = 4Y\_{23}- 2Y\_{2}-2Y\_{3}= 4\left(78.41\right)-2\left(87.50\right)-2\left(69.68\right)=-0.72$$

By inserting the above coefficient values into Equation (11), the resulting Scheffe’s regression model for estimating the UCS retention of corn starch-stabilized lateritic soil is expressed as follows;

$UCS\_{retention}=83.33X\_{1}+87.50X\_{2}+69.68X\_{3}+18.82X\_{1}X\_{2}+43.98X\_{1}X\_{3}-0.72X\_{2}X\_{3}$ (12)

Where; X1 represents the pseudo proportion of the lateritic soil in the corn starch stabilized soil

 X2 represents the pseudo proportion of the corn starch in the corn starch stabilized soil

 X3 represents the pseudo proportion of the water/solids ratio

Table 3 presents the results of the F-statistics used to validate the Scheffe’s regression model (Equation 12) developed to predict the UCS retention of corn starch-stabilized lateritic soil. The model was developed using experimental data from the control mixes within the framework of a statistical mixture design. In this context, the F-statistic is crucial for testing the significance of the model in explaining the observed variability in the UCS retention.

From Table 3, the calculated F-value is 1.056, which is considerably lower than the F-critical value of 5.05 at a 5% significance level (α = 0.05) and 5 degrees of freedom (df). This comparison serves as the basis for hypothesis testing: the null hypothesis (H₀), which states that the predicted UCS retention values are not significantly different from the experimental counterpart, is accepted since F-calculated < F-critical. This confirms that the residual variation is not statistically distinguishable from the model-predicted variation, indicating that the model does not overfit or underperform relative to the random variation in the data (Montgomery, 2017).

The use of F-statistics in model validation is grounded in its ability to compare explained and unexplained variances in regression analysis. A non-significant F-value, as obtained here, suggests that the regression model fits the data without introducing artificial trends or over-specifications (Kutner et al., 2005). This outcome is particularly desirable when working with empirical mixture models where parsimony and generalizability are critical.

Complementing the F-statistics is the coefficient of determination (R²) shown in Figure 5, which demonstrates a value of 0.998 or 99.8%. This remarkably high R² implies that 99.8% of the variability in UCS retention is explained by the regression model within the experimental design space. Such a high degree of fit indicates excellent predictive capability, which is critical in geotechnical applications where performance prediction under variable field conditions is essential (Myers et al., 2016).

While high R² values can sometimes be misleading, especially in over-parameterized models, this concern is mitigated by the concurrent analysis of F-statistics. The combination of a low F-value and a high R² suggests that the model is both statistically stable and predictively robust. According to Gunst and Mason (2009), when validating regression models for materials engineering, both F-statistics and R² must be interpreted jointly to ensure that model complexity does not inflate the apparent predictive accuracy.

Moreover, in geotechnical modeling of stabilized soils, prior studies also advocate for the integration of both ANOVA and R² as dual indicators of model performance. For example, Osinubi et al. (2021) and Edeh et al. (2022) have emphasized this approach in evaluating regression models for stabilized lateritic and expansive soils, reporting similar findings where low F-values and high R² signify reliable model behavior.

Therefore, based on the statistical evidence from Table 3 and Figure 5, the model for predicting UCS retention in corn starch-stabilized lateritic soil is validated as statistically adequate, robust, and highly explanatory. It can thus be reliably applied for predictive purposes in the context of mixture design optimization.

**Table 3. F-Statistics for the Validation of Scheffe’s Model for Predicting UCS retention of Corn Starch Stabilized Lateritic Soil**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **S/N** | **UCSretention Experimental Value=Yₑ** | **UCSretention Predicted or Model Value= Ym**  | **Yₑ-Ŷₑ** | **Ym-Ŷm** | **(Yₑ-Ŷₑ)²** | **(Ym-Ŷm)²** |
| 1 | 88.44 | 88.740 | 2.187 | 2.456 | 4.78151 | 6.03030 |
| 2 | 86.08 | 86.006 | -0.173 | -0.278 | 0.03004 | 0.07747 |
| 3 | 82.02 | 81.918 | -4.233 | -4.366 | 17.92111 | 19.06487 |
| 4 | 84.02 | 84.056 | -2.233 | -2.228 | 4.98778 | 4.96547 |
| 5 | 87.89 | 87.957 | 1.637 | 1.673 | 2.67868 | 2.79848 |
| 6 | 89.07 | 89.029 | 2.817 | 2.744 | 7.93361 | 7.53210 |
|  | Ŷₑ = 86.253 | Ŷm = 86.284 |  |  | ∑= 38.333 | ∑= 40.469 |
|  Square of deviation of experimental UCSretention values from mean UCSretention value | *Տ*ₑ2 | 4.792 |
|  Square of deviation of predicted UCSretention values from mean UCSretention value | *Տm*2 | 5.059 |
|  F- Calculated value, ratio of the two deviations, F-cal | **1.056** |

**Figure 5. Predicted Vs Experimental UCS retentions for Corn Starch Stabilized Soil**

**3.3 Effect of Mixture Components and their Interactions on UCS Retention of Stabilized Lateritic Soil**

The UCS retention of corn starch–stabilized lateritic soil is critically influenced by the interplay of its constituent components, namely lateritic soil, corn starch, and water/solids ratio. Equation (12) provides insight into how these factors, represented by their pseudo proportions X1, X2, and X3 respectively, affect UCS retention after exposure to durability stresses such as wetting and drying cycles.

The coefficient of 87.50 for corn starch (X2) indicates that it plays the most influential role in enhancing UCS retention. Biopolymers like corn starch are known to significantly improve the bonding between soil particles by forming gels upon hydration, which subsequently harden and bind the soil matrix (Khatami & O’Kelly, 2013). These gels enhance soil cohesion, particularly under cyclic moisture conditions, thereby contributing to better strength retention. Recent studies have shown that starch-based biopolymers improve not only the initial strength but also maintain structural integrity over time (Li et al., 2023).

The lateritic soil (X1) itself has a substantial coefficient of 83.33, showing that its inherent geotechnical properties, such as the presence of iron and aluminum oxides, offer considerable baseline strength. When stabilized, these soils exhibit high shear strength and relatively low permeability, contributing positively to UCS retention. The combined contribution of lateritic soil and corn starch is further reinforced by their positive interaction coefficient (18.82), suggesting synergistic effects when both materials are present in appropriate proportions.

Conversely, the water/solids ratio (X3) contributes the least among the primary components with a coefficient of 69.68. While water is essential for activating starch and aiding in soil compaction, an excessive amount increases porosity and weakens the matrix, reducing UCS retention. Studies by Mujah et al. (2020) and Muntohar et al. (2018) confirm that water content must be carefully controlled in biopolymer-stabilized soils to avoid loss of strength due to increased void ratios and potential leaching of binding agents.

The interaction between lateritic soil and the water/solids ratio is highly positive (43.98), suggesting that when an optimal amount of water is used with a suitable quantity of lateritic soil, the matrix benefits from enhanced cohesion and compaction. This may be attributed to the role of water in mobilizing fine particles and aiding in starch gelatinization, thereby enhancing the inter-particle bonding within the soil matrix (Ayeldeen et al., 2017).

However, the interaction between corn starch and water/solids ratio (−0.72) is slightly negative, indicating a detrimental effect when both are in high proportions. Excess water may reduce the efficiency of starch as a binder by preventing full gelatinization or causing dilution and leaching, which compromises long-term strength retention. This aligns with findings by Chang et al. (2020), who reported that biopolymer effectiveness declines beyond an optimal moisture threshold, particularly under wet-dry cycling conditions.

In conclusion, the Scheffé’s model reveals that corn starch is the most effective component in enhancing UCS retention of lateritic soil, followed by lateritic soil and then water/solids ratio. However, the optimal performance is achieved not merely by maximizing individual components but by balancing them to take advantage of positive interactions (especially X1X2 and X1X3) while minimizing negative synergistic effects like X2X3. The model thus underscores the importance of mixture proportioning in soil stabilization applications using bio-based additives.

1. **Conclusions**

Based on the experimental data, statistical modeling, and regression analysis presented in the result section, the following key conclusions can be drawn:

1. Experimental results show that both the trial and control mixes had high UCS retention values, ranging from about 69% to over 90%. This means that corn starch is very effective in improving the strength of lateritic soils, even after they go through wetting and drying cycles. When the retention values are above 80%, and especially over 90% as seen in Mix 4, it indicates that the stabilized soil is highly durable and performs well under conditions that usually weaken untreated soils.
2. With UCS retention values reaching up to 91.24%, corn starch helps the soil hold its strength more effectively. This is likely because it forms a gel that holds soil particles together and keeps moisture in balance. As a result, corn starch can be seen as a strong and eco-friendly option for stabilizing soils.
3. The Scheffe’s regression model used to predict UCS retention is very reliable. It explains almost all the changes in strength retention, showing a very strong fit between the predicted and actual results. The small difference between what was predicted and what was measured confirms that the model works well and doesn't exaggerate or miss important details. This means the model can be confidently used to estimate and improve soil stabilization results.
4. Effect analysis using the developed model coefficients shows that corn starch plays the biggest role in helping the soil keep its strength after wetting and drying. Lateritic soil also adds a good amount of strength on its own. However, the amount of water used in the mix has the least effect and needs to be carefully controlled. Too much water can create too many pores in the soil, which can weaken it over time
5. Interaction analysis revealed that when corn starch and lateritic soil are combined, they improve strength more than when used alone. A good mix of lateritic soil and water also helps by improving how well the materials stick together. However, using too much water with a lot of starch can actually reduce the soil’s strength. This happens because the starch may not work properly or might get washed out, making the binding less effective.

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